1973

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Monterey, California. Naval Postgraduate School

http://hdl.handle.net/10945/16715

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## Monterey, California

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Submitted in partial fulfillment of the
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MASTER OF SCIENCE IN OPERATIONS ANALYSIS

from the

NAVAL POSTGRADUATE SCHOOL
September 1973

## ABSTRACT

The thesis investigates the characteristics of effective teaching as perceived by students at the Naval Postgraduate School. Principal components factor analysis is used to extract the characteristics from observations on an 86 variable questionnaire form designed by Hildebrand and Wilson. The characteristics are then used as a basis for a short form questionnaire. Cluster and discriminant analysis are used to find teaching patterns or styles based on seven characteristics. Ranking schemes for evaluated instructors are also discussed.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

# I. INTRODUCTION

## A. MOTIVATION

Within the last decade, an increasing emphasis on basing evaluation of teaching and of teachers on performance in the classroom environment has taken place at many college level academic institutions throughout this country. Prior to this time, the evaluation of teaching performance of university professors took a second place to other activities that were more readily observable, such as research work published, committee work, or performance of administrative tasks. The demands of administration positions often preclude even token visits to classroom sessions.[1]

Academic administrators are, for the most part, former teachers themselves and thus probably tend to evaluate their colleagues as other teachers do. A survey conducted on the Davis Campus of the University of California provides evidence that teachers do not primarily judge each other on teaching ability in the classroom.[2] In this survey, 162 teachers chose what they considered to be the best and worst of their colleagues while also answering some informational questions concerning themselves.

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[1]Gustad, J. W., "Policies & Practices in Faculty Evaluation," The Educational Record, v. 42, p. 194-211, 1961.

[2]Milton Hildebrand and R. C. Wilson, Effective University Teaching and Its Evaluation, report to the faculty sponsored by the Academic Senate, April 1970, p. 20.

Fifty-one percent of the respondents had not observed a classroom performance of those chosen as best, while seventy-five percent had not done so for those chosen as worst. Admittedly, these judgements were relative to the respondent's own concept of what constituted a good or bad teacher, but it is surprising that a judgement can be made without some direct input from the classroom environment, the arena for a teacher's primary function. The results of this survey, coupled with the acknowledged burdens of academic administration, facilitate an understanding of how classroom observation has come to contribute so little to the administrators' evaluation of his faculty.

One form of the recent widespread effort to correct this deficiency has been the utilization of student opinion collected through questionnaires or course critique sheets. Some of this effort had its inception with student body organizations motivated by a general student desire to have a say concerning the quality of the teaching he receives while striving to attain his academic goals. At the same time, many academic administrations and faculty organizations have recognized that input from the classroom should play a greater role in teaching evaluation and that the student is qualified to provide this input.[3]

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[3]Elster, R. S., Githens, W. H., and Senger, J. D., Factors Leading to Satisfaction and Dissatisfaction With Teachers, paper presented at the Western Psychological Association Convention, 26 April 1972.

As a result of such effort, colleges and universities have developed numerous student evaluation forms, largely with the same objectives, but each different enough to have questionable applicability at any other institution. Because there are unique factors associated with a particular college or university, such as general make up of the student body, type of funding, overall faculty profile, and the type education offered, each such institution should attempt to develop its own means of tapping its largest, most up to date, and readily available data source on classroom performance of its teachers, the students.

## B. BACKGROUND

In September 1971, academic administrators and faculty at the Naval Postgraduate School initiated activity intended to determine what constituted effective teaching at that institution and to develop a means to measure it. Such measurements could then be used to assist the teacher in achieving his goals in his profession and could be used to aid the administration in its teacher evaluation task. The activities at the Naval Postgraduate School took several different forms, two of which are relevant to this thesis.

The first of these activities was the establishment of a committee within the Operations Research/Administrative Sciences Department tasked with determining the characteristics of effective teaching. In March 1972, after preliminary research, a report was published which identified the need for a thorough study to accomplish the following:

1. Identify the ways that students look at instructors.

2. Number and characterize the significant dimensions of the teaching-learning process as viewed by our students.

3. Identify patterns or stylistic differences among teachers.

4. Identify and quantify the importance of exogenous variables (e.g., subject matter, class size, core course, service course, etc.).[4]

The other form was the establishment of a Faculty Council Committee tasked with finding improved measures of teaching performance. Of the approaches suggested, one of those adopted was the employment of the recently published methods developed by Milton Hildebrand and Robert C. Wilson at the University of California, Davis Campus.[5] In December 1971 and March 1972, an instructor evaluation form developed by them was administered to students from various curricula at the Naval Postgraduate School. It was hoped that their methodology applied to these data would yield results similar to theirs and lead to an efficient means of obtaining student opinion of teaching and teachers. (See Appendix A for a summary of data collected.)

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[4] Naval Postgraduate School, On the Quantification of Teacher Performance Using Student Opinion, by R. R. Read and H. J. Zwieg, p. 44, March 1972.

[5] Milton Hildebrand, R. C. Wilson, and E. R. Dienst, Evaluating University Teaching, University of California Press, 1971.

## C. DISCUSSION OF PREVIOUS RESEARCH

Because the methods of Hildebrand and Wilson were used to generate the initial data and their results provide a basis of comparison for application of such methods, their work warrants description to the extent that it relates to this project. As part of an objective to characterize effective teaching performance and provide a basis for teaching evaluation, they developed a method to extract the components of effective teaching from student opinion questionnaires. They first developed what was termed a long form by reducing an initial list of 236 descriptions of various aspects of teaching to 85 items which were judged by students to be most discriminating between previously identified best and worst teachers. When this list had been put into questionnaire form, 119 students at the University of California, Davis Campus indicated applicability to instructors to whom they had been exposed by simple yes, no, or no opinion responses. These data were further reduced by application of principal components factor analysis with varimax rotation and yielded the following components of effective teaching:

1. Synthetic/Analytic Approach
2. Organization/Clarity
3. Instructor-Group Interaction
4. Instructor-Individual Interaction
5. Dynamism/Enthusiasm

The above descriptions of the resulting components are subjective to the extent that they are based on an interpretation of those original variables most highly correlated with each principal component of the solution. These same variables, put together in a verbal description of the

components, are the basis for a short form questionnaire. When both the long and short forms were administered simultaneously, the short form variables were found to have high correlations with the original variables on the long form. Table I shows the long form, annotated to reflect those variables which contributed significantly to the principal components solution, along with these variables' correlations with the components. These correlations are called factor loadings. Table II shows the short form variables describing the principal components.

## D. APPROACH

This research began in October 1972 with the acquisition of the raw data gathered under the sponsorship of the Faculty Council committee. The overall objective was to use these data and any other that might be obtained to satisfy the objectives of both the Faculty Council committee and the Operations Research/Administrative Sciences committee. To this end, the following basic approach was planned:

1. Employ the methodologies of factor analysis on the initial data to determine if results existed which were sharper than Hildebrand and Wilson's.

2. Employ the chosen factor analysis method to determine the components of effective teaching from the data with attention to curricula as an exogenous variable.

3. Use the components found to develop a short form questionnaire and determine its applicability and validity.

4. Employ cluster analysis to determine patterns or styles of teaching based on the components of effective teaching previously determined.

5. Investigate the dimensionality of student perception of teaching and their evaluations of teachers.

6. Respond to other questions that present themselves during the course of the research.

TABLE I

LIST OF CHARACTERISTICS

| PRINCIPAL COMPONENT | LOADING | COURSE CONTENT AND PRESENTATION: |
|---|---|---|
| 1 | .66 | 1. Contrasts implications of various theories |
| 1 | .60 | 2. Presents origins of ideas and concepts |
| 1 | .53 | 3. Presents facts and concepts from related fields |
| | | 4. Talks about research he has done himself |
| | | 5. Emphasizes ways of solving problems rather than solutions |
| | | 6. Discusses practical applications |
| | | 7. Explains his actions, decisions, and selection of topics |
| | | 8. Seems well read beyond the subject he teaches |
| | | 9. Is an excellent public speaker |
| | | 10. Speaks clearly |
| | | 11. Explains clearly |
| 2 | .78 | 12. Gives lectures that are easy to outline |
| 2 | .62 | 13. Reads his lectures or stays close to his notes |
| | | 14. Assigns text as background, but lectures include other topics |
| | | 15. Makes difficult topics easy to understand |
| 2 | .51 | 16. Summarizes major points |
| 2 | .50 | 17. States objectives for each class session |
| 2 | .47 | 18. Identifies what he considers important |
| | | 19. Shows interest and concern in quality of his teaching |
| | | 20. Gives examinations requiring creative, original thinking |
| | | 21. Gives examinations having instructional value |
| | | 22. Gives examinations requiring chiefly recall of facts |
| | | 23. Gives interesting and stimulating assignments |
| | | 24. Stresses the aesthetic and emotional value of the subject |
| 5 | .80 | 25. Is a dynamic and energetic person |
| 5 | .74 | 26. Seems to enjoy teaching |
| 5 | .65 | 27. Is enthusiastic about his subject |
| 5 | .64 | 28. Seems to have self-confidence |
| 5 | .63 | 29. Varies the speed and tone of his voice |
| 5 | .53 | 30. Has a sense of humor |

TABLE I (Cont'd)

LIST OF CHARACTERISTICS

| PRINCIPAL COMPONENT | LOADING | RELATIONS WITH STUDENTS: |
|---|---|---|
| 2 | .61 | 31. Is careful and precise in answering questions |
| | | 32. Explains his own criticisms |
| 3 | .70 | 33. Encourages class discussion |
| 3 | .65 | 34. Invites students to share their knowledge and experiences |
| 3 | .64 | 35. Clarifies thinking by identifying reasons for questions |
| 3 | .62 | 36. Invites criticism of his own ideas |
| 3 | .58 | 37. Knows if the class is understanding him or not |
| 3 | .57 | 38. Knows when students are bored or confused |
| 3 | .43 | 39. Has students apply concepts to demonstrate understanding |
| | | 40. Keeps well informed about progress of class |
| | | 41. Anticipates difficulties and prepares students beforehand |
| | | 42. Has definite plan, yet uses material introduced by students |
| | | 43. Provides time for discussion and questions |
| | | 44. Is sensitive to student's desire to ask a question |
| | | 45. Encourages students to speak out in lecture or discussion |
| | | 46. Quickly grasps what a student is asking or telling him |
| | | 47. Restates questions or comments to clarify for entire class |
| | | 48. Asks others to comment on one student's contribution |
| | | 49. Compliments students for raising good points |
| | | 50. Answers questions fully |
| | | 51. Determines if one student's problem is common to others |
| | | 52. Reminds students to see him if having difficulty |
| | | 53. Informs students of coming campus events related to course |

TABLE I (Cont'd)

LIST OF CHARACTERISTICS

| PRINCIPAL COMPONENT | LOADING | RELATIONS WITH STUDENTS (Cont'd) |
|---|---|---|
| | | 54. Encourages students to express feeling and opinions |
| 4 | .74 | 55. Relates class topics to students' lives and experiences |
| 4 | .69 | 56. Has a genuine interest in students |
| 4 | .68 | 57. Relates to students as individuals |
| 4 | .64 | 58. Recognizes and greets students out of class |
| | | 59. Is valued for advice not directly related to the course |
| | | 60. Treats students as his equals |
| | | OTHER CHARACTERISTICS: |
| 1 | .70 | 61. Discusses points of view other than his own |
| 1 | .64 | 62. Discusses recent developments in the field |
| 1 | .53 | 63. Gives references for the more interesting and involved points |
| 1 | .46 | 64. Emphasizes conceptual understanding |
| | | 65. Disagrees with some ideas in textbook and other readings |
| | | 66. Stresses rational and intellectual aspects of the subject |
| | | 67. Stresses general concepts and ideas |
| | | 68. Seems to have a serious commitment to his field |
| 2 | .63 | 69. Is well prepared |
| | | 70. Gives examinations stressing conceptual understanding |
| | | 71. Gives examinations requiring synthesis of various parts of course |
| | | 72. Gives examinations permitting students to show understanding |
| 4 | .71 | 73. Is friendly toward students |
| 4 | .65 | 74. Is accessible to students out of class |
| 4 | .60 | 75. Respects students as persons |
| | | 76. Is always courteous to students |
| | | 77. Gives personal help to students having difficulty with course |

TABLE I (Cont'd)

LIST OF CHARACTERISTICS

| PRINCIPAL COMPONENT | LOADING | OTHER CHARACTERISTICS (Cont'd) |
| --- | --- | --- |
| 5 | .76 | 78. Has an interesting style of presentation |
| | | *79. Was constrained by having to meet a rigorous course outline |
| | | SUMMARY OF IMPRESSIONS OF INSTRUCTOR's COURSES: |
| | | 80. Have developed increased appreciation for the subject |
| | | 81. Have learned new ways to evaluate problems |
| | | 82. Have worked harder than in most other courses |
| | | 83. Know how to find more information on the subject |
| | | 84. Have studied a topic from the course on own initiative |
| | | 85. Plan to take more courses on the subject |
| | | 86. Have gained self-knowledge |

*This variable was not on Hildebrand and Wilson's original list but was added by the Faculty Committee

TABLE II

SHORT FORM VARIABLES DEVELOPED BY HILDEBRAND AND WILSON FROM THE PRINCIPAL COMPONENTS SOLUTION OF THEIR LONG FORM STUDENT OPINION QUESTIONNAIRE

1. (Synthetic/Analytic Approach)[6] Has command of the subject, presents material in an analytic way, contrasts various points of view, discusses current developments, and relates topics to other areas of knowledge.

2. (Organization/Clarity) Makes himself clear, states objectives, summarizes major points, presents material in an organized manner, and provides emphasis.

3. (Instructor-Group Interaction) Is sensitive to the response of the class, encourages student participation, and welcomes questions and discussion.

4. (Instructor-Individual Interaction) Is available and friendly towards students, is interested in students as individuals, is respected as a person, and is valued for advice not directly related to the course.

5. (Dynamism/Enthusiasm) Enjoys teaching, is enthusiastic about his subject, makes the course exciting, and has self-confidence.

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[6] Parenthetical remarks were not included on the short form questionnaire but have been included here for clarity.

## II. THEORY OF VARIABLES

### A. FACTOR ANALYSIS MODEL

Factor analysis, in the most simplistic definition, is a mathematical means of finding a more parsimonious representation of a data set. the variables of which are too numerous and too complex in their interrelationships to be efficiently analyzed by the more basic statistical methodologies. It seeks a more regular and orderly representation through a reduction in the number of variables, while retaining a significant proportion of the information contained in the original data's variance-covariance structure. There are two basic types of factor analysis, principal components and classical. The former is generally used when extraction of a maximum of the variance is desired with the reduction of a large body of data, while the latter is used when a maximal reproduction of the correlations is desired.[7] In addition, there are a number of methods of solution improvement, called rotations, which have been developed to render the factor structure more easily interpretable.[8]

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[7] Harman, H. H., Modern Factor Analysis, p. 15, The University of Chicago Press, 1967.

[8] Morrison, D. F., Multivariate Statistical Methods, p. 277-286, McGraw-Hill, 1967.

Principal component factor analysis with Kaiser's varimax rotation was chosen for this research effort primarily because it was used by Hildebrand and Wilson in their work and it was anticipated that a comparison of results could be made.

The principal components method is based on the model that the original variables, the characteristics listed in the long form questionnaire in this case, can be expressed in a linear combination of hidden or latent variables called the principal components. Algebraically:

$$Z_j = a_{j1}F_1 + a_{j2}F_2 + - - - - - - - + a_{jn}F_n$$

where $Z_j$ is the standardized representation of the original variable $x_{ij}$,

$j = 1, 2,$ --------, n variables,

$i = 1, 2,$ --------, N observations.

The $F_i$'s are the new uncorrelated, mutually orthogonal components representing the latent variables and the $a_{ji}$'s are the correlations, called factor loadings, of the original variables with the components.[9]

In a geometric interpretation, the original data in n-space is projected onto mutually orthogonal axes. These axes are then rotated so that the first axis is aligned in the direction of maximum variance of the original data and each succeeding axis is aligned in the direction of next largest variance maintaining orthogonalty during the successive rotation.

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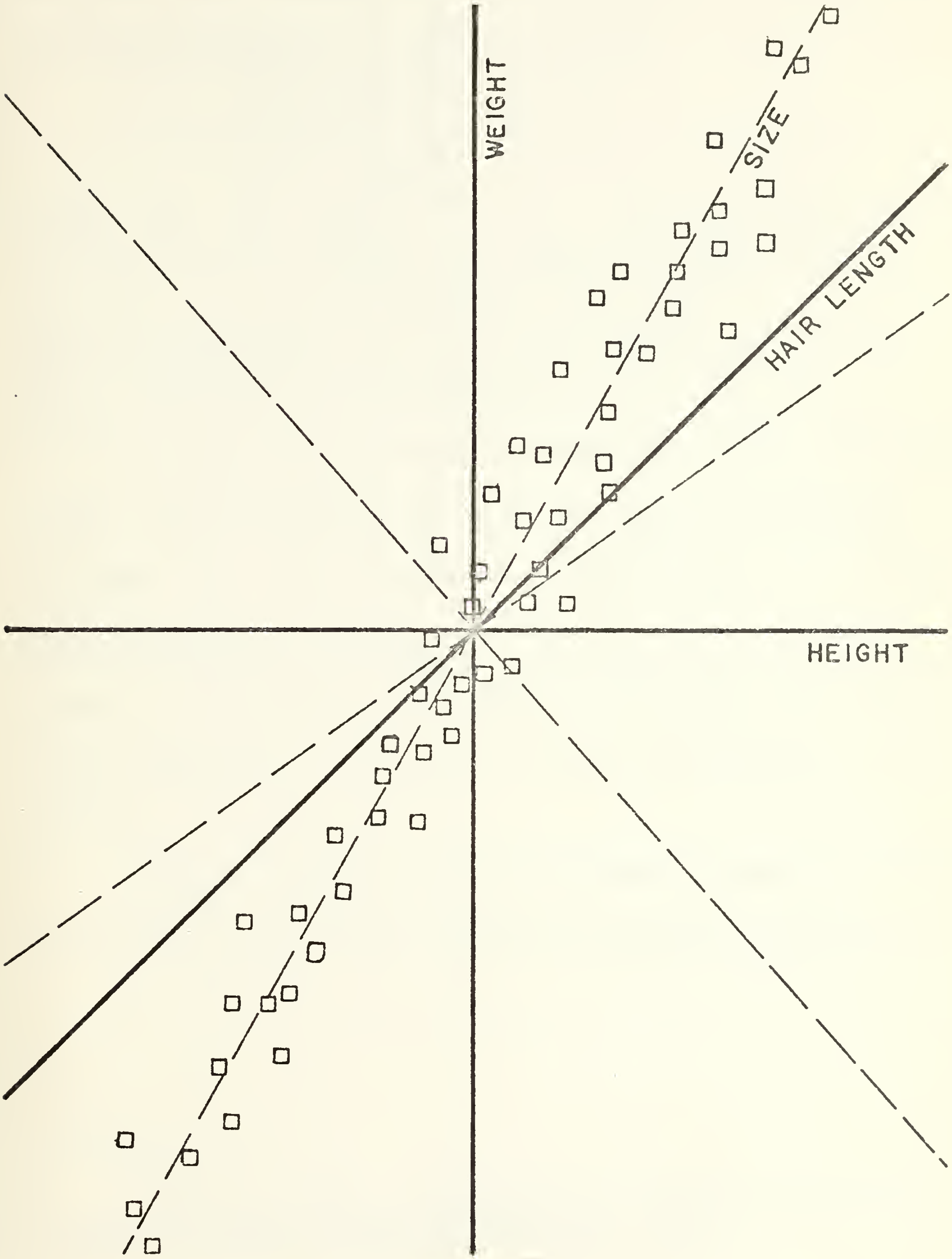
[9]If the model is for the non-standardized representation of the original variables, the $a_{ji}$'s are not considered as correlations.

In the model, $F_1$ represents the dimension of greatest variability and for the data in question, is the component of teaching most discriminated upon by the respondents. The $a_{j1}$, $j = 1, 2, \text{--------}, n$, represents the contribution of the original variable j to the first principal component, $F_1$. Geometrically, it may be interpreted as a direction cosine. As a simple geometric example, consider Figure 1. In this figure, three original variables are represented by the solid axes. The variables are height, weight, and hair length of a population of generally short haired people. The data points plotted show considerable variability in the first two dimensions and little in the third. Now, rotating the axes and aligning one with the direction of greatest variance (represented by the broken lines), shows virtually all the variability as being in one dimension. Because the example is known to have little variability with regard to hair length, the other variables are the ones which contribute to the make up of the new variable which might be called "size." The contributions of the original variables to the new variables are measured by the direction cosines of the angles between the old axes and the new. This example illustrates essentially what happens in principal components analysis with the exceptions that: there are generally many more dimensions to start with, and a very small percentage of the new dimensions contain a large percentage of the original variance.

A more rigorous explanation is given by Anderson, presented here without proof:

FIGURE 1. GEOMETRIC EXAMPLE
PRINCIPAL COMPONENTS ANALYSIS



Theorem:

Let the n-component random vector Z have $E(Z) = 0$ and $E(Z^t Z) = \Sigma$. Then there exists an orthogonal linear transformation $U = B^t Z$ such that the covariance matrix of U, $E(U^t U) = \Lambda$ and

$$\Lambda = \begin{pmatrix} \lambda_1 & & 0 \\ & \lambda_2 & \\ 0 & & \ddots \ \lambda_n \end{pmatrix}$$

where $\lambda_1 \leq \lambda_2 \leq ----- \leq \lambda_n$, are the roots of $|\Sigma - \lambda I| = 0$. The rth column of B, $B^{(r)}$ satisfies $(\Sigma - \lambda I) B = 0$. The rth component of U, $U_r = B^{(r)} Z$ and has maximum variance of all linear combinations uncorrelated with $U_1$, $U_2$ ----, $U_{r-1}$.[10]

For this model, the B matrix is the eigenvector matrix of the original data's covariance structure and its entries, the $a_{ji}$'s are the factor loadings. The $\lambda_i$'s are the proportion of the total variance associated with component i. The sum of the $\lambda_i$, i = 1,-----, n, equals the total variance of the principal components and is also equal to the total variance of the original data. The number $\lambda_i$ is also the eigenvalue of component $F_i$, i = 1, 2,-----, n.

There are, according to the above Theorem, as many new variables after rotation and projection as there were originally. Parsimony is

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[10] Anderson, T. W., An Introduction to Multivariate Statistical Analysis, p. 276, John Wiley and Sons, Inc., 1958.

realized when a significant percentage of the original variance is represented by the first few components. These are retained and the remaining components can be ignored.

## B. PRINCIPAL COMPONENT INTERPRETATION

There may be a problem in deciding just how many of the principal components to retain when arriving at a final solution when the number of original variables is large. When the number is not large, there are tests which may be applied which indicate the proper cutoff.[11] These tests will also give a result for the case of a large number of original variables, but the result may indicate that many more components should be retained than are necessary or desired. For example, an exchange of 86 variables for 55 new variables will most likely not be a useful data reduction. What is commonly done is to base the number to be retained on prior knowledge of the structure of the data or to retain only those components that can be interpreted from the factor loadings. Morrison states:

> "It has been the author's experience that if that proportion (an arbitrarily large percentage of the total variance) cannot be explained by the first four or five components, it is usually fruitless to persist in extracting vectors (components), for even if the later characteristic roots (eigenvalues) are sufficiently distinct to allow easy computation of the components, the interpretation of the components may be difficult if not impossible."[12]

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[11] Harman, <u>op. cit</u>., p. 219-221.

[12] Morrison, <u>op. cit</u>., p. 228.

Interpretation of a principal component is accomplished by subjective evaluation of the interaction of the factor loadings, the $a_{ji}$'s, in the column of the loading matrix associated with the component. Recall that these loadings are the correlations of the original variables with the principal components. By considering those variables with the highest factor loadings it is possible to ascribe an overall impression of what the component description is. For example, consider Table III which shows the first column of the factor loading matrix from a principal components solution on the initial data. The highest loadings are underlined and ordinally ranked. In Table IV, these loadings, the variables with which they are associated, and the variable description are listed in decreasing order of contribution to the component. The original variables 11, 31, 37, 50, and 15 seem to imply a characteristic of clarity while 12, 16, 69, and 17 seem to imply organization. A possible subjective description of the latent variable, the principal component, would be Clarity and Organization.

The interpretation of each successive principal component is accomplished in the same manner. The order of interpretation is that of decreasing contribution to the total variance or the decreasing eigenvalues. However, as the eigenvalues associated with the components decrease, so too do the magnitudes of the higher factor loadings, the tendency being for each column to show a greater number of the original variables with loadings that are considered to be high for the column but low

TABLE III

EXAMPLE OF THE FIRST COLUMN OF THE MATRIX OF COEFFICIENTS OF THE PRINCIPAL COMPONENTS FACTOR SOLUTION TO BE USED TO INTERPRET THE DESCRIPTION OF THE FIRST FACTOR

| VARIABLE | LOADING | | VARIABLE | LOADING | |
|---|---|---|---|---|---|
| 1 | .37700 | | 44 | .17808 | |
| 2 | .24275 | | 45 | .15283 | |
| 3 | .40222 | | 46 | .43623 | |
| 4 | .15269 | | 47 | .18707 | |
| 5 | .27606 | | 48 | -.09353 | |
| 6 | .39737 | | 49 | .09479 | |
| 7 | .40413 | | 50 | .60175 | 5 |
| 8 | .35573 | | 51 | .20575 | |
| 9 | .31561 | | 52 | .08014 | |
| 10 | .18101 | | 53 | -.01084 | |
| 11 | .66136 | 1 | 54 | .10357 | |
| 12 | .61633 | 3 | 55 | .17331 | |
| 13 | .31673 | | 56 | .29736 | |
| 14 | .05576 | | 57 | .12527 | |
| 15 | .54326 | 7 | 58 | .09250 | |
| 16 | .50656 | 8 | 59 | .34866 | |
| 17 | .48285 | 10 | 60 | .24600 | |
| 18 | .46128 | | 61 | .09676 | |
| 19 | .41122 | | 62 | .16384 | |
| 20 | .22018 | | 63 | .06223 | |
| 21 | .34127 | | 64 | .20938 | |
| 22 | -.00843 | | 65 | .03449 | |
| 23 | .30931 | | 66 | .23559 | |
| 24 | .00475 | | 67 | .16664 | |
| 25 | .20287 | | 68 | .35832 | |
| 26 | .28835 | | 69 | .50099 | 9 |
| 27 | .22526 | | 70 | .19880 | |
| 28 | .14762 | | 71 | .26968 | |
| 29 | .07290 | | 72 | .29485 | |
| 30 | .18059 | | 73 | .07791 | |
| 31 | .63895 | 2 | 74 | .06014 | |
| 32 | .19004 | | 75 | .14191 | |
| 33 | .03289 | | 76 | .15093 | |
| 34 | .07870 | | 77 | .17045 | |
| 35 | .24359 | | 78 | .31987 | |
| 36 | .14032 | | 79 | .07016 | |
| 37 | .60848 | 4 | 80 | .26556 | |
| 38 | .46292 | | 81 | .24285 | |
| 39 | .24362 | | 82 | .21790 | |
| 40 | .56442 | 6 | 83 | .13387 | |
| 41 | .46630 | | 84 | -.03767 | |
| 42 | .21039 | | 85 | .10786 | |
| 43 | .11598 | | 86 | .08458 | |

TABLE IV

LIST OF VARIABLE DESCRIPTIONS IN ORDER OF DECREASING LOADINGS FOR EXAMPLE IN TABLE III

| LOADING | VARIABLE # | DESCRIPTION |
|---|---|---|
| .66136 | 11 | Explains clearly |
| .63895 | 31 | Is careful and precise in answering questions |
| .61633 | 12 | Gives lectures that are easy to outline |
| .60848 | 37 | Knows if class is understanding him |
| .60175 | 50 | Answers questions fully |
| .56442 | 40 | Keeps well informed about the progress of the class |
| .54326 | 15 | Makes difficult topics easy to understand |
| .50656 | 16 | Summarizes major points |
| .50099 | 69 | Is well prepared |
| .48285 | 17 | States objectives for each class session |

relative to the loadings on the previously determined components. This makes interpretation more difficult than for earlier components. At some point, the value of the associated eigenvalue will be less 1.0. This implies that the component contributes less to the total variance than did any one of the original variables. Those components with associated eigenvalues greater or equal to 1.0 and with factor loadings that render the component interpretable are the ones to be retained.

With respect to the data of this research effort, the retained components constitute a model of the components of effective teaching as perceived by the students, and their number represents the dimensionality of such perceptions. It is important to note that the components describe what the students discriminate on among teachers as a result of the dependence of the method on the variance-covariance structure of the original data. It is quite possible that other components of effective teaching may be considered important by the respondents but may fail to show up in the principal components solution. For example, should all of the instructors score high on those variables that contribute to a component that might be interpreted as Evaluation Technique, the contribution of this component to the total variance would be small compared to that of components with a full range of high and low marks. In this case, the component might not show up in the final solution.

## C. FACTOR SCORES

While meaningful results are embodied in the principal component solution as it stands, the descriptions and dimensionality can be used to gain further useful information. The vector of responses on the original variables can be transformed into a smaller vector of responses on the new variables which in theory retain a significant amount of the original information. It then becomes tenable to apply other methods of statistical analysis, which would be intractable otherwise, to the data in its reduced dimensioned form. For example, the results of a cluster analysis applied to a data set of 86 variables would probably be difficult to interpret, and require unreasonable computing power. However, the same methodology applied to the much smaller number of variables resulting from the principal components solution would usually have more easily interpreted results. A factor scoring transformation matrix is used to accomplish this reduction of the data's dimension.

The factor scoring transformation matrix is computed by multiplication of the matrix of component correlations, the matrix of factor loadings, and the variance-covariance matrix of the original data. The resulting matrix is then applied to each vector of responses from the original data. This yields a vector which has a one to one correspondence with the characteristics of effective teaching as determined by the principal components solution and may be thought of as the responses that the student might have given had he been asked to evaluate the particular instructor directly on the new variables.

Given a principal components solution of p components, the individual entries in the factor scoring transformation matrix of size (pxn) are computed by the BMDX72 Factor Analysis Program as follows:[13]

$$k_{jc} = \sum_{ab} c_{ja} u_{ab} s_{bc}$$

where $c_{ja}$ is the correlation of component j with component a

$u_{ab}$ is the factor loading of original variable b on component a

$s_{bc}$ is the covariance of original variable b with original variable c

$a = 1, 2, \text{------}, p$

$b = 1, 2, \text{------}, n$

$c = 1, 2, \text{------}, n$

$j = 1, 2, \text{------}, p$

$n$ = number of original variables

$p$ = number of retained components

The vector of p factor scores for observation i is then computed by multiplying the vector of n original data scores by the above matrix. The computation of the individual scores of the vector of factor scores is as follows:

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[13] Dixon, W. J., University of California Publications in Automatic Computations, No. 3, BMD Biomedical Computer Programs, X-series Supplement, p. 90-103, University of California Press, Berkeley and Los Angeles, 1969.

$$f_{ji} = \sum_{c} k_{jc} z_{ci}$$

where $z_{ci}$ is the standardized score on original variable c for observation i

$i = 1, 2, ------, N$

N = Total number of observations

Each $f_{ji}$ is a representation of the information contained in the original data expressed in terms of the component of effective teaching j for each observation i. Some information is lost in the transformation but this loss is offset by the more parsimonious representation of the students' opinions or perceptions.

## D. THE SHORT FORM VARIABLES

The ultimate worth of the determination of the components of effective teaching is their employment in the development of a short form questionnaire that will not overly tax the respondent but will still produce the information desired. The approach used by Hildebrand and Wilson was to combine the descriptions of the original variables used to interpret each component to form a single composite description of that component and use it as a short form variable. Responses were to be made on a psychological scale of 1 to 7 to indicate degree of applicability to the evaluated instructor. To help illustrate how this is done, the original variable descriptions listed in Table IV, which led to an interpretation of a component called Organization and Clarity, are reproduced below in order of decreasing factor loadings.

| VARIABLE NUMBER | DESCRIPTION |
|---|---|
| 11 | Explains clearly |
| 31 | Is careful and precise in answering questions |
| 12 | Gives lectures that are easy to outline |
| 37 | Knows if class is understanding him |
| 50 | Answers questions fully |
| 40 | Keeps well informed about the progress of the class |
| 15 | Makes difficult topics easy to understand |
| 16 | Summarizes major points |
| 69 | Is well prepared |
| 17 | States objectives for each class session |

These descriptions might be reworded and put together as follows:

> He makes himself clear, makes his objectives known, summarizes major points, is well prepared, presents material in an organized manner, and is aware of class progress and understanding.

The subjective interpretation (Organization and Clarity) does not appear in the composite description so the respondent remains focused on the combination of original variables and is not prompted to respond on the interpretation alone. Short form variables are similarly constructed for each of the components resulting from a given principal component solution so that the short form questionnaire will have a variable for each component.

## E. LADDER SCORES

In order to compare this study with that of Hildebrand and Wilson and to give direction to the components discovered, it was necessary to compile lists of best and worst instructors. It had been shown in

previous research that a ladder technique can serve this purpose.[14] The technique provides additional data on the respondents ranking of each instructor relative to the other instructors he evaluated. For these reasons, the ladder ranking of instructors was required of each respondent for all data sets collected for this study.

For completeness, a description of the ladder technique follows. Figure 2 shows a fifteen step ladder which was used to represent the students one dimensional ranking of teachers. To use the ladder, the student was asked to think of the very best and very worst teachers he had ever been exposed to in his entire academic experience and place them at the top and bottom of the ladder, respectively. He was then to rank all teachers he had been exposed to from an eligible teacher list provided. Ties were permitted. He also was to indicate a minimum acceptable level of teaching performance on this ladder.

The rankings were converted to range scaled scores (0.0 to 1.0) for each student and then averaged for each instructor. This provided a simple representation of the ranking by the students, as a group, for all instructors evaluated. This ranking might then be used for comparison with ranking schemes constructed from the questionnaire data in original or transformed form.

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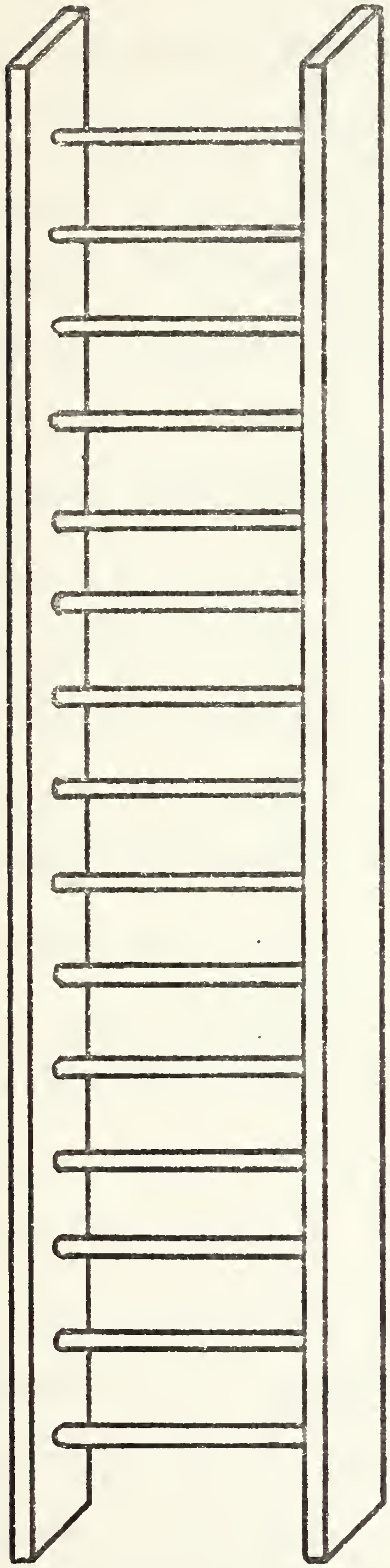
[14] Read and Zwieg, op. cit., p. 5-8.

FIGURE 2. LADDER SCALE OF OVERALL TEACHING EFFECTIVENESS EVALUATION FORM



ABSOLUTE BEST

15 ________________

14 ________________

13 ________________

12 ________________

11 ________________

10 ________________

9 ________________

8 ________________

7 ________________

6 ________________

5 ________________

4 ________________

3 ________________

2 ________________

1 ________________

ABSOLUTE WORST

## III. ANALYTICAL RESULTS

### A. PRINCIPAL COMPONENTS ANALYSIS

Determination of what constitutes effective teaching is the most important objective of this research effort. It was anticipated that the methods of Hildebrand and Wilson would be used to accomplish this. It was first necessary to ensure that their method could not be improved upon. The first step was then that of subjecting the initial data, collected under the sponsorship of the Faculty Council Committee, to both types of factor analysis with all possible rotation options. This was done with the December 1971 data and there was no appreciable improvement of any one solution over any other. Therefore all subsequent factor analysis was done using the principal components method. As a byproduct of this testing, the principal components solution for the December data was obtained.

The December 1971 data consisted of 1089 observations provided by 109 students from three graduate curricula, 49 from Management (curriculum 817), 41 from Computer Systems Management, and 19 from Electrical Engineering. From a given list of instructors, each respondent ranked all he had known in the classroom environment on the 15 step ladder and then evaluated the top and bottom five using the long form list of characteristics developed by Hildebrand and Wilson with addition of one more variable, (number 79). The applicability of each characteristic was indicated by (+) applied, (0) can't say or don't know, or (-) does

not apply. These responses were then converted into numbers and analyzed using BMDX72- Factor Analysis on the Naval Postgraduate School IBM-360/67 Computer.

The results of the analysis on the first data set are shown in Table V. Each column contains ordered pairs, the first of which is the original variable number from the long form list, followed by its factor loading. Where possible, the top ten loadings are shown in order of decreasing magnitude. It may occur that the magnitude of the ninth or tenth loading is not significant compared with the magnitude of the higher loadings, in this case only the significant loadings are included. In fact such a situation is desirable for it generally results in a very clear interpretation of that component. Such is the case for the component labeled Dynamism and Enthusiasm. At the top of each column is the component's interpretation, and at the bottom of each column, the associated eigenvalue and the cumulative percent of the total variance.

The data set analyzed was heterogeneous in that respondents were from three different curricula. This was intentional because Hildebrand and Wilson developed their methods using heterogeneous samples. It is observed that the five components found by them at the Davis Campus of the University of California also appear in this solution. However, the order of these components is changed, and there are two additional components, Evaluation Technique and Stimulation. Table VI lists the components of this solution in order and also shows where they appeared in the Davis results.

COMPONENT DESCRIPTIONS

| LOADINGS IN ORDER OF MAGNITUDE | ORGANIZATION AND CLARITY | INSTRUCTOR INDIVIDUAL INTERACTION | EVALUATION TECHNIQUE | ANALYTIC SYNTHETIC APPROACH | STIMULATION | DYNAMISM AND ENTHUSIASM | INSTRUCTOR GROUP INTERACTION |
|---|---|---|---|---|---|---|---|
| 1 | 12, .68 | 56, .54 | 14, .49 | 63, .54 | 20, -.57 | 9, .55 | 48, .58 |
| 2 | 11, .62 | 73, .49 | 2, .47 | 62, .51 | 82, -.46 | 25, .54 | 36, .54 |
| 3 | 17, .60 | 58, .49 | 79, -.44 | 55, .45 | 22, .42 | 29, .44 | 34, .51 |
| 4 | 31, .60 | 60, .48 | 65, .35 | 85, .45 | 84, -.41 | 78, .42 | 54, .49 |
| 5 | 16, .60 | 76, .46 | 8, .33 | 24, .41 | 71, -.38 | 26, .42 | 47, .43 |
| 6 | 69, .59 | 19, .41 | 6, .33 | 3, .41 | 21, -.38 | 23, .36 | 42, .41 |
| 7 | 15, .56 | 30, .40 | 34, .32 | 59, .39 | 72, -.37 | 27, .35 | 49, .40 |
| 8 | 18, .55 | 75, .40 | 22, -.30 | 53, .39 | 70, -.33 | 13, -.31 | 55, .36 |
| 9 | 40, .55 | 44, .40 | 3, .29 | 2, .37 | 23, -.32 | 28, .30 | 35, .35 |
| 10 | 37, .54 | 74, .49 | 33, .29 | 6, .35 | 39, -.31 | | 57, .35 |
| Associated Eigenvalue | 2 21.25 | 3.29 | 1.88 | 1.48 | 1.33 | 1.26 | 1.16 |
| Cumulative Percent of Variance | .306 | .353 | .380 | .401 | .421 | .439 | .456 |

TABLE V. PRINCIPAL COMPONENTS SOLUTION FOR 1089 OBSERVATIONS FROM DECEMBER 1971 EXPERIMENT - ALL CURRICULA COMBINED

TABLE VI

COMPARISON OF PRINCIPAL COMPONENTS SOLUTION ORDER WITH HILDEBRAND AND WILSON SOLUTION

| DECEMBER 1971 COMPONENT | H+W ORDER |
|---|---|
| 1. Organization and Clarity | 2 |
| 2. Instructor Individual Interaction | 4 |
| 3. Evaluation Technique | - |
| 4. Synthetic/Analytic Approach | 1 |
| 5. Stimulation | - |
| 6. Dynamism and Enthusiasm | 5 |
| 7. Instructor Group Interaction | 3 |

In order to investigate the effect of the curriculum as an exogenous variable, the individual curricula of the December 1971 data were subjected to principal components analysis separately. These solutions are shown in Tables VII, VIII, and IX.

The last three solutions presented have differences in the order and number of the components resulting from the factor analysis. Most important is the difference in the first component of the Computer Systems Management Curriculum. Here Organization and Clarity appears as the last component while Dynamism and Enthusiasm is first. For the components associated with smaller eigenvalues, switching and loss or gain of the components can be expected from one solution to another. The first component makes the greatest contribution to the overall variance and a switch such as this indicates a significant difference due to the curriculum. It could be hypothesized that the shift took place because organization and clarity are common to the teachers in the computer discipline, and less variance in response to variables that constitute that component's interpretation was observed. Checking back to the means and variances of the original variables showed that instructors in this curriculum did score high on these variables, and the variances were smaller than those of variables that were associated with the other components. The evidence, at this point, indicated that it is possible that principal components solutions for this type of data may depend not only on the make up of the student body, but also on the particular curriculum of the respondents.

COMPONENT DESCRIPTIONS

| LOADINGS IN ORDER OF MAGNITUDE | ORGANIZATION AND CLARITY | INSTRUCTOR GROUP INTERACTION | INSTRUCTOR INDIVIDUAL INTERACTION | SYNTHETIC ANALYTIC APPROACH | EVALUATION TECHNIQUE | DYNAMISM AND ENTHUSIASM | STIMULATION |
|---|---|---|---|---|---|---|---|
| 1 | 11, .66 | 34, .58 | 60, .61 | 63, .52 | 20, .55 | 25, .56 | 22, .57 |
| 2 | 31, .64 | 33, .51 | 56, .61 | 84, .50 | 21, .54 | 9, .44 | 80, -.40 |
| 3 | 12, .62 | 48, .50 | 57, .52 | 85, .49 | 72, .54 | 29, .43 | 23, -.37 |
| 4 | 37, .61 | 79, -.49 | 52, .45 | 62, .49 | 70, .49 | 26, .39 | 81, -.37 |
| 5 | 50, .60 | 54, .47 | 73, .41 | 59, .48 | 39, .48 | 78, .37 | 84, -.37 |
| 6 | 40, .56 | 13, -.45 | 49, .40 | 55, .43 | 71, .45 | 2, .34 | 86, -.29 |
| 7 | 15, .54 | 42, .42 | 19, .40 | 61, .43 | 47, .42 | 27, .33 | 46, -.28 |
| 8 | 16, .51 | 45, .42 | 76, .39 | 4, .41 | 78, .38 | 1, .33 | 9, -.24 |
| 9 | 69, .50 | 14, .41 | 58, .38 | 2, .33 | 38, .34 | 3, .32 | 20, -.23 |
| 10 | 17, .48 | 82, -.39 | 54, .38 | 3, .33 | 25, .34 | 24, .31 | 49, -.22 |
| Associated Eigenvalue | 18.31 | 3.85 | 2.12 | 1.63 | 1.49 | 1.39 | 1.26 |
| Cumulative Percent of Variance | .274 | .333 | .364 | .389 | .411 | .432 | .451 |

TABLE VII. PRINCIPAL COMPONENTS SOLUTION FOR 488 OBSERVATIONS FROM DECEMBER 1971 EXPERIMENT-MANAGEMENT 817 CURRICULUM

COMPONENT DESCRIPTIONS

| LOADINGS IN ORDER OF MAGNITUDE | DYNAMISM AND ENTHUSIASM | INSTRUCTOR GROUP INTERACTION | SYNTHETIC ANALYTIC APPROACH | INSTRUCTOR INDIVIDUAL INTERACTION | STIMULATION | ORGANIZATION AND CLARITY | |
|---|---|---|---|---|---|---|---|
| 1 | 25, .58 | 34, .62 | 22, -.59 | 58, .52 | 82, .51 | 12, -.67 | |
| 2 | 29, .53 | 45, .62 | 20, .46 | 56, .50 | 84, .48 | 17, -.60 | |
| 3 | 27, .52 | 48, .58 | 3, .40 | 60, .46 | 52, .44 | 16, -.59 | |
| 4 | 26, .47 | 54, .54 | 2, .39 | 73, .46 | 85, .38 | 11, -.59 | |
| 5 | 9, .47 | 33, .52 | 5, .33 | 76, .44 | 23, .34 | 69, -.57 | |
| 6 | 19, .38 | 42, .49 | 1, .31 | 44, .44 | 59, .33 | 15, -.55 | |
| 7 | 30, .37 | 51, .48 | 60, .30 | 77, .42 | 40, .32 | 18, -.52 | |
| 8 | 78, .37 | 49, .47 | 6, .29 | 75, .41 | 71, .32 | 64, .51 | |
| 9 | 15, .35 | 43, .45 | 72, .29 | 19, .40 | 78, .30 | 50, -.51 | |
| 10 | 41, 35 | 55, .45 | 23, .28 | 30, .39 | | 70, -.51 | |
| Associated Eigenvalue | 24.52 | 3.02 | 1.97 | 1.68 | 1.53 | 1.35 | |
| Cumulative Percent of Variance | .350 | .393 | .423 | .445 | .467 | .487 | |

TABLE VIII. PRINCIPAL COMPONENTS SOLUTION FOR 402 OBSERVATIONS FROM DECEMBER 1971 EXPERIMENT-COMPUTER SYSTEMS MANAGEMENT CURRICULUM

COMPONENT DESCRIPTIONS

| LOADINGS IN ORDER OF MAGNITUDE | ORGANIZATION AND CLARITY | SYNTHETIC ANALYTIC APPROACH | EVALUATION TECHNIQUE | INSTRUCTOR INDIVIDUAL INTERACTION | STIMULATION | INSTRUCTOR GROUP INTERACTION | |
|---|---|---|---|---|---|---|---|
| 1 | 69, .74 | 62, .76 | 14, .64 | 34, .63 | 45, -.65 | 50, .48 | |
| 2 | 12, .73 | 63, .72 | 22, -.62 | 48, .57 | 33, -.51 | 60, .46 | |
| 3 | 11, .68 | 6, .69 | 65, .60 | 51, .53 | 47, -.48 | 32, .38 | |
| 4 | 37, .67 | 3, .60 | 5, .56 | 38, .52 | 44, -.48 | 54, .37 | |
| 5 | 40, .65 | 24, .59 | 42, .49 | 41, .48 | 49, -.40 | 73, .37 | |
| 6 | 50, .64 | 55, .58 | 20, .48 | 16, .48 | 43, -.38 | 19, .36 | |
| 7 | 19, .61 | 35, .51 | 21, .47 | 56, .47 | 8, -.36 | 27, .34 | |
| 8 | 80, .61 | 53, .51 | 82, .42 | 59, .46 | 7, -.33 | 61, .34 | |
| 9 | 31, .60 | 57, .50 | 15, .39 | 77, .45 | 1, -.33 | 49, .32 | |
| 10 | 72, .57 | 61, .47 | 32, .37 | | 36, -.33 | 76, .31 | |
| Associated Eigenvalue | 21.61 | 4.23 | 3.31 | 3.09 | 2.21 | 1.96 | |
| Cumulative Percent of Variance | .299 | .357 | .402 | .446 | .476 | .504 | |

TABLE IX. PRINCIPAL COMPONENTS SOLUTION FOR 189 OBSERVATIONS FROM DECEMBER 1971 EXPERIMENT-ELECTRICAL ENGINEERING CURRICULUM

The March 1972 data set, also collected under the sponsorship of the Faculty Council committee, provided an additional 278 observations by 47 students, 159 by 27 Operations Research/Systems Analysis students, 49 by eight Oceanography students, and 70 by 12 Meteorology students. There was a difference in that each student evaluated the top, middle, and bottom two instructors from his ladder. The inclusion of the middle rankings was intended to provide insight into the effect on the principal components solution of a full range of teaching performance evaluations. This was felt to be appropriate since any methodology developed would be applied to all types of instructors, not just the best and worst. The first analysis was on the heterogeneous sample of all 278 observations. The results are shown in Table X.

When compared to the December 1971-All Data solution, it is apparent that the components of Evaluation Technique and Dynamism and Enthusiasm do not appear. The first component is the same, however. It was not possible to say whether the inclusion of the middle ranked instructors caused a reduction in the variability of the variables which make up these components to such a degree that they failed to appear.

Analysis of the individual curricula of this data set was confined to the Operations Research/Systems Analysis Curriculum because the number of observations in each of the other two was too small compared to the number of original variables. This situation was found to result in meaningless solutions in this and prior projects employing factor analysis methods. The solution is shown in Table XI and, with the

COMPONENT DESCRIPTIONS

| LOADINGS IN ORDER OF MAGNITUDE | ORGANIZATION AND CLARITY | INSTRUCTOR GROUP INTERACTION | SYNTHETIC ANALYTIC APPROACH | STIMULATION | INSTRUCTOR INDIVIDUAL INTERACTION | | |
|---|---|---|---|---|---|---|---|
| 1 | 69, -.71 | 45, .60 | 62, -.50 | 84, .69 | 13, .48 | | |
| 2 | 11, -.68 | 54, .60 | 66, -.47 | 85, .55 | 4, -.38 | | |
| 3 | 37, -.67 | 34, .58 | 14, -.46 | 59, .35 | 57, .35 | | |
| 4 | 41, -.67 | 33, .56 | 65, -.44 | 86, .34 | 76, .33 | | |
| 5 | 50, -.66 | 55, .55 | 20, -.42 | 83, .31 | 75, .31 | | |
| 6 | 12, -.65 | 36, .55 | 67, -.42 | 81, .29 | 56, .29 | | |
| 7 | 15, -.65 | 60, .52 | 63, -.42 | 42, .28 | 83, .27 | | |
| 8 | 46, -.62 | 48, .49 | 21, -.41 | 24, .28 | 74, .27 | | |
| 9 | 38, -.61 | 30, .44 | 71, -.41 | 23, .26 | 73, .25 | | |
| 10 | 9, -.60 | 44, .41 | 70, -.38 | 48, .26 | 52, .25 | | |
| Associated Eigenvalue | 19.98 | 3.34 | 2.28 | 1.58 | 1.53 | | |
| Cumulative Percent of Variance | .316 | .369 | .405 | .430 | .454 | | |

TABLE X. PRINCIPAL COMPONENTS SOLUTION FOR 278 OBSERVATIONS FROM MARCH 1972 EXPERIMENT-COMBINED OPERATIONS ANALYSIS, METEOROLOGY, AND OCEANOGRAPHY CURRICULA

COMPONENT DESCRIPTIONS

| LOADINGS IN ORDER OF MAGNITUDE | ORGANIZATION AND CLARITY | INSTRUCTOR GROUP INTERACTION | SYNTHETIC ANALYTIC APPROACH | STIMULATION | | | |
|---|---|---|---|---|---|---|---|
| 1 | 69, .73 | 33, .64 | 64, .59 | 85, .58 | | | |
| 2 | 37, .72 | 54, .63 | 22, -.56 | 84, .57 | | | |
| 3 | 50, .71 | 45, .63 | 70, .54 | 59, .39 | | | |
| 4 | 12, .71 | 34, .60 | 1, .53 | 83, .36 | | | |
| 5 | 11, .70 | 48, .55 | 21, .53 | 15, .32 | | | |
| 6 | 41, .69 | 55, .55 | 20, .53 | 35, .31 | | | |
| 7 | 10, .67 | 53, .53 | 66, .51 | 86, .29 | | | |
| 8 | 38, .66 | 61, .48 | 59, .47 | 65, .28 | | | |
| 9 | 31, .63 | | 5, .46 | 66, .28 | | | |
| 10 | 15, .63 | | 63, .46 | | | | |
| Associated Eigenvalue | 22.37 | 4.22 | 2.38 | 1.74 | | | |
| Cumulative Percent of Variance | .341 | .406 | .442 | .469 | | | |

TABLE XI. PRINCIPAL COMPONENTS SOLUTION FOR 159 OBSERVATIONS FOR MARCH 1972 EXPERIMENT-OPERATIONS ANALYSIS CURRICULUM

exception of the loss of one component, is very much like the solution for all the March 1972 data. This might be expected since this curriculum provides 57 percent of the data.

To provide a larger data base for heterogeneous solutions, the December 1971 and March 1972 data were combined. The 1367 observations were subjected to principal component analysis, yielding the solution shown in Table XII. While this solution is not significantly different from the one obtained for the 1089 observations of the December 1971 data alone, it is worth noting that four of the components had less than ten high factor loadings before a large magnitude drop in the loading was observed. This situation is desirable because it makes the interpretation of the components considerably easier.

It was observed with this solution that the component previously interpreted to be Dynamism and Enthusiasm might be better labeled Presentation Technique. Reconsideration of the preceding solutions of this project and of the work of Hildebrand and Wilson supported this conclusion. While they chose the original interpretation, and that interpretation was ascribed to these solutions because of the recurrence of the contributing variables, not all of those variables can be considered to be contributing to Dynamism and Enthusiasm. All can, however, be ascribed to Presentation Technique.

It was observed from the previous solutions that there appear to be seven components of effective teaching at the Naval Postgraduate

COMPONENT DESCRIPTIONS

| LOADINGS IN ORDER OF MAGNITUDE | ORGANIZATION AND CLARITY | INSTRUCTOR INDIVIDUAL INTERACTION | STIMULATION | INSTRUCTOR GROUP INTERACTION | EVALUATION TECHNIQUE | PRESENTATION TECHNIQUE (D+E) | SYNTHETIC ANALYTIC APPROACH |
|---|---|---|---|---|---|---|---|
| 1 | 12, .66 | 60, .54 | 84, .55 | 34, -.58 | 20, -.58 | 9, .47 | 62, -.49 |
| 2 | 11, .63 | 73, .48 | 85, .51 | 48, -.55 | 22, .50 | 25, .44 | 3, -.48 |
| 3 | 37, .61 | 58, .48 | 23, .40 | 45, -.53 | 21, -.43 | 26, .43 | 6, -.43 |
| 4 | 50, .60 | 52, .43 | 59, .38 | 33, -.51 | 72, -.40 | 29, .42 | 63, -.43 |
| 5 | 69, .60 | 76, .43 | 63, .33 | 54, -.51 | 71, -.40 | 27, .35 | 14, -.42 |
| 6 | 31, .59 | 57, .41 | 86, .31 | 36, -.45 | 82, -.40 | 28, .35 | 2, -.41 |
| 7 | 41, .58 | 19, .40 | 24, .31 | 42, -.45 | 70, -.37 | 78, .35 | 4, -.41 |
| 8 | 15, .58 | 77, .39 | 55, .30 | 49, -.39 | 39, -.30 | 13, .31 | 1, -.40 |
| 9 | 17, .57 | 74, .38 | 80, .30 | 55, -.36 | 5, -.28 | | |
| 10 | 38, .57 | 75, .37 | | 43, -.36 | | | |
| Associated Eigenvalue | 20.96 | 3.13 | 1.92 | 1.45 | 1.28 | 1.15 | 1.10 |
| Cumulative Percent of Variance | .307 | .352 | .380 | .401 | .420 | .437 | .453 |

TABLE XII. PRINCIPAL COMPONENTS SOLUTION FOR 1368 OBSERVATIONS FROM COMBINED DATA FROM DECEMBER 1971 AND MARCH 1972 EXPERIMENTS

School, but not all show up in any given solution. It also appears there is a higher likelihood of all seven components resulting when using data from mixed curricula and with a large number of observations.

The preceding work generates the following questions. Will a larger sample of data from a particular curriculum reinforce the results of a smaller sample from the same curriculum or tend toward the results of the larger mixed samples? What is the effect on the solution of the inclusion of the middle ranked instructors?

To answer the above questions, two additional sets of data were collected. The first was obtained in March 1973 and consisted of 243 observations by 28 students from the Operations Research/Systems Analysis Curriculum on the three top, middle, and bottom ranked instructors on their ladders. The second was obtained in May 1973 and consisted of 507 observations by 51 students from the Management 817 Curriculum on the five top and bottom instructors from their ladders. The same 86 variable long form list of characteristics was used in both data collections.

The principal components analysis solution for the March 1973 data is shown in Table XIII. It differs from the preceding Operations Research/Systems Analysis solution in that Synthetic Analytic Approach does not appear while Evaluation Technique and Instructor Individual Interaction do. It cannot be said that this solution reinforces the preceding one for the same curriculum (see Table XI).

COMPONENT DESCRIPTIONS

| LOADINGS IN ORDER OF MAGNITUDE | ORGANIZATION AND CLARITY | INSTRUCTOR INDIVIDUAL INTERACTION | STIMULATION | INSTRUCTOR GROUP INTERACTION | EVALUATION TECHNIQUE | | |
|---|---|---|---|---|---|---|---|
| 1 | 11, -.72 | 45, .58 | 86, -.58 | 48, .49 | 22, -.63 | | |
| 2 | 69, -.69 | 57, .55 | 81, -.53 | 62, .47 | 70, .47 | | |
| 3 | 78, -.66 | 56, .53 | 71, -.43 | 53, .47 | 21, .46 | | |
| 4 | 31, -.65 | 33, .53 | 80, -.43 | 54, .46 | 20, .37 | | |
| 5 | 12, -.65 | 60, .51 | 83, -.42 | 59, .45 | 72, .33 | | |
| 6 | 50, -.64 | 73, .50 | 70, -.36 | 63, .45 | 67, .29 | | |
| 7 | 37, -.64 | 76, .50 | 23, -.35 | 34, .42 | 54, .29 | | |
| 8 | 41, -.59 | 75, .46 | 67, -.33 | 55, .41 | 71, .26 | | |
| 9 | 9, -.58 | 43, .45 | 77, -.29 | 24, .41 | 44, .26 | | |
| 10 | 40, -.58 | 30, .44 | | 7, .41 | 38, .25 | | |
| Associated Eigenvalue | 20.05 | 3.35 | 2.37 | 1.92 | 1.70 | | |
| Cumulative Percent of Variance | .315 | .363 | .400 | .431 | .457 | | |

TABLE XIII. PRINCIPAL COMPONENTS SOLUTION FOR 243 OBSERVATIONS FROM MARCH 1973 EXPERIMENT-OPERATIONS ANALYSIS CURRICULUM

To investigate the effect on the principal components solution of including the middle ranked instructors, it was necessary to have a data set with a sufficient number of observations such that when the middle ranked instructors were removed, the remaining number of observations was large enough with respect to the number of original variables. Neither of the data sets that had evaluated such instructors was large enough, so the two were combined. They were then analyzed with and without the observations on the middle ranked instructors. The solution for the combined set of 402 observations had six components, all of which had appeared in either of the two solutions of the March data. With the exception of some minor shifting of the order of components with small eigenvalues, the solution for the set with the middle ranked instructors removed was the same. Inclusion of these observations had no effect on the principal components solution.

The results of the principal components analysis of the May 1973 data are shown in Table XIV. The results for this data set were somewhat startling. All previous solutions, with the exception of one, had Organization and Clarity as the first component. Here the component split with Clarity coming first with the greatest amount of the total variance, followed by Organization. As might be expected, when the covariation of those variables associated with the component interpreted as Clarity with those associated with the component interpreted as Organization was checked, the values were comparatively low. It was apparent that the second group of Management 817 students did not

COMPONENT DESCRIPTIONS

| LOADINGS IN ORDER OF MAGNITUDE | CLARITY | ORGANIZATION | INSTRUCTOR STUDENT INTERACTION | STIMULATION | EVALUATION TECHNIQUE | SYNTHETIC ANALYTIC APPROACH | |
|---|---|---|---|---|---|---|---|
| 1 | 78, -.70 | 12, .62 | 56, -.64 | 85, .62 | 71, .50 | 4, .45 | |
| 2 | 9, -.70 | 17, .52 | 60, -.60 | 84, .59 | 70, .50 | 79, .40 | |
| 3 | 29, -.61 | 16, .51 | 57, -.58 | 86, .44 | 21, .49 | 1, .39 | |
| 4 | 25, -.57 | 13, .50 | 36, -.54 | 59, .43 | 72, .47 | 13, .39 | |
| 5 | 11, -.56 | 31, .45 | 54, -.52 | 23, .42 | 20, .44 | 2, .38 | |
| 6 | 38, -.55 | 18, .44 | 52, -.51 | 14, .42 | 64, .41 | 64, .36 | |
| 7 | 15, -.51 | 69, .41 | 34, -.47 | 63, .40 | 83, .39 | 34, .36 | |
| 8 | 28, -.50 | | 30, -.45 | 55, .38 | 39, .38 | 3, .35 | |
| 9 | 37, -.48 | | 49, -.45 | 80, .35 | 81, .37 | | |
| Associated Eigenvalue | 19.37 | 3.01 | 2.68 | 1.64 | 1.49 | 1.27 | |
| Cumulative Percent of Variance | .309 | .357 | .400 | .426 | .450 | .470 | |

TABLE XIV. PRINCIPAL COMPONENTS SOLUTION FOR 507 OBSERVATIONS FROM MAY 1973 EXPERIMENT-MANAGEMENT 817 CURRICULUM

feel the same way about the instructors that the first group had. This fact is also illustrated by the merging of the two components previously defined as Instructor Individual Interaction and Instructor Group Interaction into one component called Instructor Student Interaction.

There were nine instructors that were evaluated by both of these groups. They were ranked according to their average range scaled ladder scores for both groups and the Spearman Rank Order Correlation Coefficient was computed and found to be .27. This is further evidence that any two groups of respondents from the same curriculum may look at instructors in a different manner.

Table XV shows the principal components solution for all Management 817 data collected and Table XVI shows the same for all data collected for this research project.

It appears that even though the combined Management 817 solution reinforces the December 1971 Management 817 solution, it is also tending toward the solutions for the mixed December 1971 All and March 1972 All solution, as well as the solution for all collected data. It also is evident that there are fewer original variables with high enough loadings to be used in component interpretation as the number of observations gets higher. This is clearly the case for the 2107 observations from all data sets where at least ten significant loadings could not be found for five of the seven components.

COMPONENT DESCRIPTIONS

| LOADINGS IN ORDER OF MAGNITUDE | ORGANIZATION AND CLARITY | INSTRUCTOR GROUP INTERACTION | INSTRUCTOR INDIVIDUAL INTERACTION | STIMULATION | EVALUATION TECHNIQUE | PRESENTATION TECHNIQUE (D+E) | SYNTHETIC ANALYTIC APPROACH |
|---|---|---|---|---|---|---|---|
| 1 | 12, .65 | 79, -.49 | 56, .62 | 84, .61 | 20, .56 | 9, .60 | 80, .45 |
| 2 | 11, .61 | 34, .47 | 60, .60 | 85, .53 | 70, .54 | 29, .58 | 81, .42 |
| 3 | 31, .60 | 82, -.45 | 57, .56 | 63, .49 | 72, .50 | 25, .57 | 2, .34 |
| 4 | 50, .58 | 13, -.43 | 52, .50 | 59, .48 | 21, .49 | 78, .56 | 3, .31 |
| 5 | 37, .57 | 33, .40 | 54, .45 | 55, .46 | 71, .48 | 26, 42 | 4, .30 |
| 6 | 16, .54 | 4, .35 | 73, .43 | 14, .40 | 64, .37 | 38, .37 | 85, .28 |
| 7 | 69, .54 | 48, .38 | 19, .44 | 23, .46 | 39, .41 | 28, .39 | 1, .29 |
| 8 | 15, .53 | 14, .33 | 49, .43 | 62, .36 | | 15, .36 | 66, .25 |
| 9 | 40, .52 | 45, .30 | 36, .41 | 48, .35 | | 11, .36 | 6, .25 |
| 10 | 17, .51 | 54, .29 | 75, .41 | | | | 7, .24 |
| Associated Eigenvalue | 18.64 | 3.31 | 2.23 | 1.58 | 1.32 | 1.24 | 1.16 |
| Cumulative Percent of Variance | .289 | .340 | .374 | .399 | .419 | .439 | .456 |

TABLE XV. PRINCIPAL COMPONENTS SOLUTION FOR 995 OBSERVATIONS FROM COMBINED MANAGEMENT CURRICULA DATA - DECEMBER 1971 AND MAY 1973

COMPONENT DESCRIPTIONS

| LOADINGS IN ORDER OF MAGNITUDE | ORGANIZATION AND CLARITY | INSTRUCTOR INDIVIDUAL INTERACTION | INSTRUCTOR GROUP INTERACTION | SYNTHETIC ANALYTIC APPROACH | EVALUATION TECHNIQUE | PRESENTATION TECHNIQUE (D+E) | STIMULATION |
|---|---|---|---|---|---|---|---|
| 1 | 11, .65 | 56, .56 | 48, .59 | 81, .45 | 20, .58 | 29, .55 | 85, .51 |
| 2 | 50, .59 | 60, .52 | 34, .55 | 80, .44 | 21, .51 | 9, .52 | 84, .49 |
| 3 | 37, .59 | 73, .49 | 4, .49 | 86, .40 | 70, .48 | 25, .50 | 59, .39 |
| 4 | 15, .58 | 57, .47 | 54, .48 | 83, .35 | 71, .47 | 28, .38 | 23, .34 |
| 5 | 31, .57 | 52, .44 | 55, .46 | 6, .33 | 72, .46 | 78, .38 | 78, .34 |
| 6 | 38, .55 | 76, .43 | 33, .46 | 1, .32 | 82, .39 | 26, .32 | 82, .30 |
| 7 | 12, .55 | 58, .42 | 14, .44 | 2, .31 | 39, .38 | 10, .31 | 60, .27 |
| 8 | 69, .53 | 75, .41 | 45, .40 | | | 27, .31 | |
| 9 | 16, .52 | 44, .41 | 42, .40 | | | | |
| 10 | 41, .52 | 74, .39 | | | | | |
| Associated Eigenvalue | 19.97 | 2.71 | 1.83 | 1.69 | 1.34 | 1.09 | 1.05 |
| Cumulative Percent of Variance | .308 | .350 | .378 | .404 | .425 | .442 | .458 |

TABLE XVI. PRINCIPAL COMPONENTS SOLUTION FOR 2107 OBSERVATIONS FROM ALL DATA COMBINED

## B. RANKING

The use of instructors average range scaled scores computed from the student ladder rankings has been mentioned in conjunction with showing that the overlapping instructors of the Management 817 curriculum data sets were not perceived, by the two groups of students, in quite the same manner. The one dimensional ranking based on these scores is the simplest representation of how a group of respondents ranks the individual instructor on the average. At the same time the May 1973 Management 817 data was being collected from 51 students of that curriculum, a short form developed from the preceding Management 817 data's principal components solution was administered to 29 students of the same input. Both groups ranked the same set of instructors on the same one dimensional ladder. The two groups' average rankings based on the average range scaled scores were compared and found to have a Spearman's Rank Order Correlation Coefficient of .958. The short form group's ranking compared with the December 1971 group's for the nine overlapping instructors resulted in a coefficient of .35. Here is additional evidence that these two groups from the same curriculum and same input, did not perceive the instructors as did the earlier group.

All data sets mentioned in the preceding section were factor scored once the principal components solutions had been found. It was hoped that these scores could be used to find a means of converting the reduced data space model of the students' perceptions to one dimension. It was observed that assigning numerical values to the long form

variables, such as (+1, 0, -1) for (applicability, don't know, non-applicability), adding the 86 responses and ranking the evaluated instructors on the resulting sums, resulted in a fairly accurate reproduction of a student's ladder. It was decided to use the factor scores in a similar manner. First, the average factor score vector was computed for each instructor. Then four rankings were constructed based on the sum of the averaged factor scores, the sum of these scores weighted by the eigenvalue, the sum of these scores weighted by the square root of the eigenvalues, and the sum of these scores weighted by the cube root of the eigenvalues. The weighting schemes were an attempt to use the relative importance of the individual components on which each factor score was computed. The Spearman Rank Order Correlation Coefficients for these rankings compared to that based on the averaged range scaled scores for the December 1971 Management 817 data set were .65, .80, .786, and .753 respectively. The implication from these results appears to be that the variability of each component, as manifested by the associated eigenvalue, should be considered in such ranking schemes if reproduction of the one dimensional ranking is desired. It is not immediately clear which of the above schemes is best since the three weighted ones are fairly close in the rank order correlation coefficients and their difference is not statistically significant.

## C. IDENTIFICATION OF TEACHING PATTERNS FROM FACTOR SCORES

Having identified the components of effective teaching by principal components factor analysis of the various data sets, effort was turned to attempting to determine patterns or styles of teaching based on these components. Such patterns may be helpful to the instructor seeking to improve himself and to the evaluating administrator seeking to classify instructors on teaching performance.

While it is theoretically possible to identify teaching patterns based on the data from the long form questionnaires, it is not practical for two reasons. First, computing requirements for that many variables taxes the memory assets of the machine. Second, explaining such patterns would be extremely difficult. The parsimmonious representation of the original data by the factor scores which retain 45-50 percent of the information while reducing the number of variables by 90-95 percent provides a tenable solution for both of the problems.

To identify the teaching patterns, the average factor scores of each instructor evaluated in a particular data set would be cluster analyzed and the means of each cluster would be hypothesized as defining a particular pattern or style of teaching. The immediate problem is that cluster solutions of any size,up to the extreme of each vector of scores being a single cluster,are possible. It was thought that ranking reproduction or discriminant analysis or both could be used to find the solution for which the homogeneous groups of instructors defined by the clusters would be most distinct from each other.

To test this approach, the December 1971 Management 817 data set factor scores were averaged for each instructor and the averaged scores cluster analyzed by a k-iterative means clustering program.[15] Solutions for two through seven clusters with the associated vector of means for each cluster in the solution are shown in Table XVII. Instructors are represented by letters of the alphabet to maintain confidentiality, the letters being assigned according to the average range scaled score ranking based on the student ladders. This ranking appears in the left hand column. The individual clusters are arranged to preserve this ranking within the cluster to provide insight as to the ranking reproduction ability of each solution. Note that, by mere inspection, it appears that the four cluster solution best reproduces the alphabet. Solution five and six appear almost as good as each other.

Because the number of groups that can be discriminant analyzed must be less than or equal to the number of variables, work in this area was limited to seven clusters. Cluster solutions two through seven were subjected to a discriminant analysis program.[16] For this method of analysis, a test statistic is computed based on the null hypothesis that

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[15] McRae, D. J., MICKA: A Fortran IV Iterative K-means Cluster Analysis Program, CTB/McGraw Hill: Del Monte Research Park, Monterey, California, September, 1970.

[16] The discriminant analysis program consisted primarily of the subroutines DMATX and DISCR from the IBM Scientific Subroutine Package available at the Naval Postgraduate School Computer Center.

TABLE XVII
CLUSTER SOLUTION

Ranked instructors (LOW to HIGH): A B C D E F G H I J K L M N O P Q R S T U V W X Y Z

| Number of clusters | Cluster | Instructors | Values |
|---|---|---|---|
| 2 | | A B C D I O P S T X | .044, -.531, -.664, -.176, .046, -.232, .248 |
| 2 | | E F G H J K L M N Q R U V W Y Z | -.038, .278, .337, .102, -.053, .143, -.103 |
| 3 | | A B C D I O P S T X | .044, -.531, -.664, -.176, .046, -.232, .248 |
| 3 | | K M N | -.199, -.513, 1.033, -.754, .198, .302, .130 |
| 3 | | E F G H J L Q R U V W Y Z | -.001, .461, .175, .300, -.111, .107, -.156 |
| 4 | (1) | A B C D | -.922, -.387, -1.090, -.081, -.193, -.441, .493 |
| 4 | (2) | E F G H J L | -.322, .678, .303, .119, -.728, -.381, -.104 |
| 4 | (3) | I P X | .543, -.592, -.754, -.015, .141, .302, .426 |
| 4 | (4) | K M N O Q R S T U V W Y Z | .294, -.124, .272, -.037, .333, .240, -.138 |
| 5 | (1) | A B C D | -.922, -.387, -1.090, -.081, -.193, -.441, .493 |
| 5 | (2) | E F G H J L | -.322, .678, .303, .119, -.728, -.381, -.104 |
| 5 | (3) | I P X | .543, -.592, -.754, -.015, .141, .302, .426 |
| 5 | (4) | K M N O R S T | .354, -.572, .505, -.470, .236, -.043, -.009 |
| 5 | (5) | Q U V W Y Z | .225, .400, .000, .469, .445, .569, -.288 |
| 6 | (1) | A B C D | -.922, -.387, -1.090, -.081, -.193, -.441, .493 |
| 6 | (2) | E G L | -.439, .783, .024, .282, -.913, -.313, -.475 |
| 6 | (3) | F H J M | -.131, .299, .716, -.282, -.443, -.219, .149 |
| 6 | (4) | I P X | .543, -.592, -.754, -.015, .141, .302, .426 |
| 6 | (5) | K N O R S T | .397, -.508, .430, -.383, .302, -.128, .224 |
| 6 | (6) | Q U V W Y Z | .225, .400, .000, .469, .445, .569, -.288 |
| 7 | | A B C D | -.922, -.387, -1.090, -.081, -.193, -.441, .493 |
| 7 | | E G L | -.439, .783, .024, .282, -.913, -.313, -.475 |
| 7 | | F H J | -.205, .574, .582, -.043, -.539, -.449, .267 |
| 7 | | I O P S X | .647, -.577, -.455, -.186, .197, -.134, .187 |
| 7 | | K M N | -.199, -.513, 1.033, -.754, .198, .302, .130 |
| 7 | | Q U V | -.088, .459, -.086, .454, .575, .708, -.613 |
| 7 | | R T W Y Z | .616, -.068, .142, .263, .288, .322, .000 |

COMPONENTS:
1. ORGANIZATION AND CLARITY
2. INSTRUCTOR INDIV.INTERACTION
3. EVALUATION TECHNIQUE
4. SYNTHETIC ANALYTIC APPROACH
5. STIMULATION
6. PRESENTATION TECHNIQUE
7. INSTRUCTOR GROUP INTERACTION

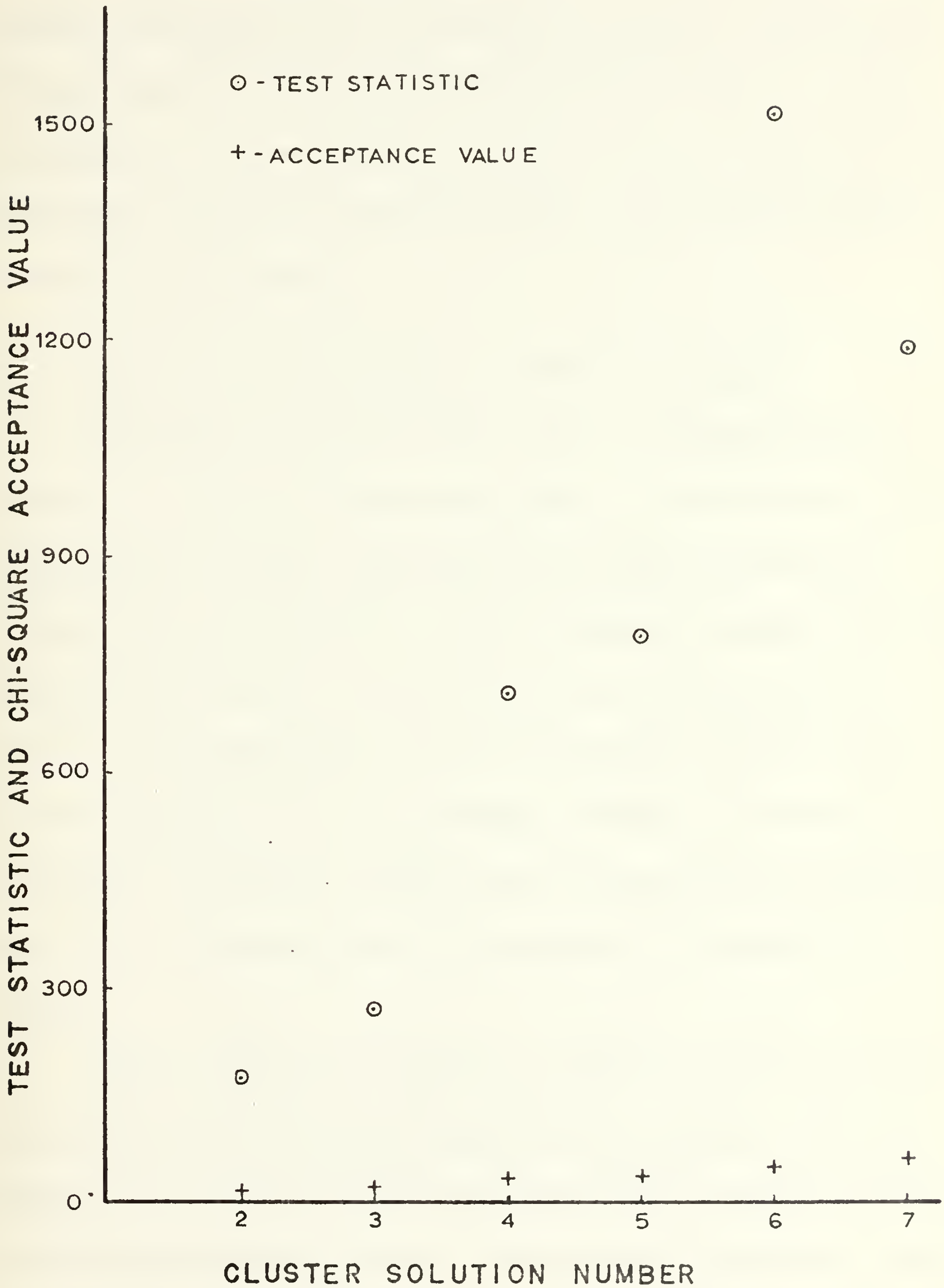
the means of the clusters are the same. A test statistic greater than the acceptance value implies that there is sufficient discrimination between the means of the clusters to reject the null hypothesis. The greater the magnitude, the greater the discrimination.

The test statistic is the Mahalanobis $D^2$ which can be considered to be a Chi-square variate with m(g-1) degrees of freedom, m being the number of variables, g the number of groups or clusters. Figure 3 shows the plot of the test statistic for the associated cluster solution that was put through the discriminant analysis program. The greatest value of the statistic occurs for the six cluster solution. Referring back to Table XVII there is an intuitive appeal associated with this solution for it represents the top and bottom few instructors of the original rank structure with high and low means respectively. These are the types of teaching patterns that might be expected for these extremes in the spectrum of teaching performance. Nothing, however, can be said regarding the middle of any of the cluster solutions being labeled good or bad by virtue of the cluster means.

The rank order correlations for each of the cluster solutions in Table XVII with the average range scaled score ranking are as follows:

| CLUSTER SOLUTION | COEFFICIENT |
|---|---|
| TWO | .690 |
| THREE | .610 |
| FOUR | .944 |
| FIVE | .936 |
| SIX | .933 |
| SEVEN | .910 |

FIGURE 3. PLOT OF TEST STATISTIC AND CHI-SQUARE ACCEPTANCE VALUE VERSUS THE NUMBER OF CLUSTERS FOR THE INSTRUCTOR AVERAGED FACTOR SCORES FROM DECEMBER 1971 MANAGEMENT 817 DATA



It appears from these results that solutions for four, five, and six clusters are about equal in rank reproduction.

To facilitate comparison of the individual groups within the cluster solutions with high rank order correlations, a graphical representation of group means for each component of effective teaching is contained in Appendix B. Cluster solutions 4, 5, and 6 shown in Table XVII, have the individual clusters numbered to provide a cross reference between the table and the appendix.

## D. SHORT FORM AND TEACHING PATTERNS BASED ON IT

Unfortunately, the use of factor scores to determine teaching pattern or styles has only experimental merit. It would hardly be practical to administer a long form questionnaire each time it was desired to evaluate a group of instructors, subject the data to principal components analysis, factor score it, then go through cluster and discriminant analysis. The determination would be much easier if a short form of the few components of effective teaching, known to be perceived by the respondents, as variables could be used to acquire the same information. Such a form was designed and used successfully by Hildebrand and Wilson.

An initial problem with the above approach was that for the initial Naval Postgraduate School data analyzed by the principal components method, no clear general solution had been found. Because there might be differences between curricula, it was decided to restrict this approach to a single curriculum, in this case the Management 817 Curriculum.

This curriculum was chosen because it was the largest of the individual data sets and it was felt that it would be possible to administer separate long and short forms to two sufficiently large groups simultaneously because of the usually large inputs to the curriculum. Correlation studies could then be done between the long and short form results.

Table XVIII shows the short form variables that were developed from the principal components analysis of the December 1971 Management 817 data. It was administered in May 1973 to 29 students of the Management 817 curriculum while 51 students of the same curriculum were administered the long form. As may be recalled from section A. of this chapter, the May 1973 principal components solution was not at all similar to the December 1971 solution. So while responses to the short form were obtained, it was not possible to compare them with the long form results.

It was decided to apply the previously described methods of cluster and discriminant analysis to this data to see if teaching patterns could be obtained, even though it was not clear whether the short form variables reflected the respondents perception of the components of effective teaching. These results are shown in Table XIX and Figure 4. Here again, the six cluster solution was indicated as best by discriminant analysis. Note that the means are now all positive because the responses were made on a scale of 1-7. The Spearman Rank Order Correlation Coefficients of the cluster solutions with the average range scaled score ranking were:

| CLUSTER SOLUTION | COEFFICIENT |
|---|---|
| TWO | .870 |
| THREE | .870 |
| FOUR | .980 |
| FIVE | .947 |
| SIX | .988 |
| SEVEN | .964 |

Graphical representation of cluster solutions 4, 5, and 6 is provided in Appendix C in the same manner as was done for cluster solutions on factor scores in section C.

TABLE XVIII

SHORT FORM VARIABLES DEVELOPED FROM DECEMBER 1971 MANAGEMENT 817 CURRICULUM

1. He makes himself clear, makes his objectives known, summarizes major points, is well prepared, presents material in an organized manner, is aware of class progress and understanding.

2. He is sensitive to the response of the class, encourages student participation through questions and discussion and is willing to deviate from his prepared lecture or course outline to pursue points resulting from student contributions.

3. He is interested in students as individuals, treats them with respect and as equals, is available for individual consultation outside of class, and is friendly and courteous to students.

4. He has a command of his subject, discusses recent developments in the field as well as contrasting theories or points of view, has an analytical method of presenting material that includes the origins of ideas and concepts as well as full development of the subject.

5. He gives exams which require creative and original thinking, have instructional value, stress conceptual understanding, require synthesis of various parts of the course, and permit students to show their understanding of the subject.

6. He is a dynamic and energetic person who is enthusiastic about both his profession and the subject he is teaching. He has an interesting style of presentation and is an excellent public speaker.

7. His lectures and assignments have stimulated you such that you have an increased appreciation of the subject, have learned new ways to evaluate problems, and have studied a topic from the course on your own initiative.

TABLE XIX

RANKED INSTR.: LOW, A, B, C, D, E, F, G, H, I, J, K, L, M, N, O, P, Q, R, S, T, U, V, W, X, Y, Z, AA, BB, CC, DD, HIGH

CLUSTER SOLUTION

**2**

| Cluster | Instructors | Values |
|---|---|---|
| | A, B, C, D, O, Z | 2.85, 4.06, 3.84, 3.70, 2.32, 3.53, 3.10 |
| | E, F, G, H, I, J, K, L, M, N, P, Q, R, S, T, U, V, W, X, Y, AA, BB, CC, DD | 4.41, 5.13, 5.41, 5.25, 4.58, 4.84, 4.72 |

**3**

| Cluster | Instructors | Values |
|---|---|---|
| | A, B, C, D, R, X | 2.55, 4.14, 4.26, 3.91, 1.79, 3.28, 3.24 |
| | E, F, G, H, I, J, K, L, M, O, P, Q, S | 3.99, 4.54, 4.92, 4.66, 4.04, 4.16, 4.06 |
| | N, T, U, V, W, Y, Z, AA, BB, CC, DD | 5.09, 5.77, 5.77, 5.83, 5.50, 5.78, 5.42 |

**4**

| Cluster | Instructors | Values |
|---|---|---|
| (1) | A, B, C, D | 2.03, 3.05, 3.22, 2.79, 1.65, 2.42, 2.11 |
| (2) | E, F, G, H, I, J, K, L, M, O, P, Q, S | 3.99, 4.54, 4.92, 4.66, 4.05, 4.16, 4.06 |
| (3) | R, X | 3.57, 6.33, 6.33, 6.16, 2.08, 5.00, 5.50 |
| (4) | N, T, U, V, W, Y, Z, AA, BB, CC, DD | 5.09, 5.77, 5.77, 5.83, 5.50, 5.78, 5.43 |

**5**

| Cluster | Instructors | Values |
|---|---|---|
| (1) | A, B, C | 1.73, 2.71, 2.94, 2.41, 1.64, 1.86, 1.79 |
| (2) | E, F, G, H, I, N | 3.53, 4.51, 5.08, 3.93, 4.15, 3.61, 3.70 |
| (3) | D, J, K, L, M, O, P, S, CC | 4.34, 4.71, 4.86, 5.16, 4.02, 4.68, 4.47 |
| (4) | R, X | 3.57, 6.33, 6.33, 6.16, 2.08, 5.00, 5.50 |
| (5) | Q, T, U, V, W, Y, Z, AA, BB, DD | 5.06, 5.70, 5.72, 5.87, 5.36, 5.79, 5.31 |

**6**

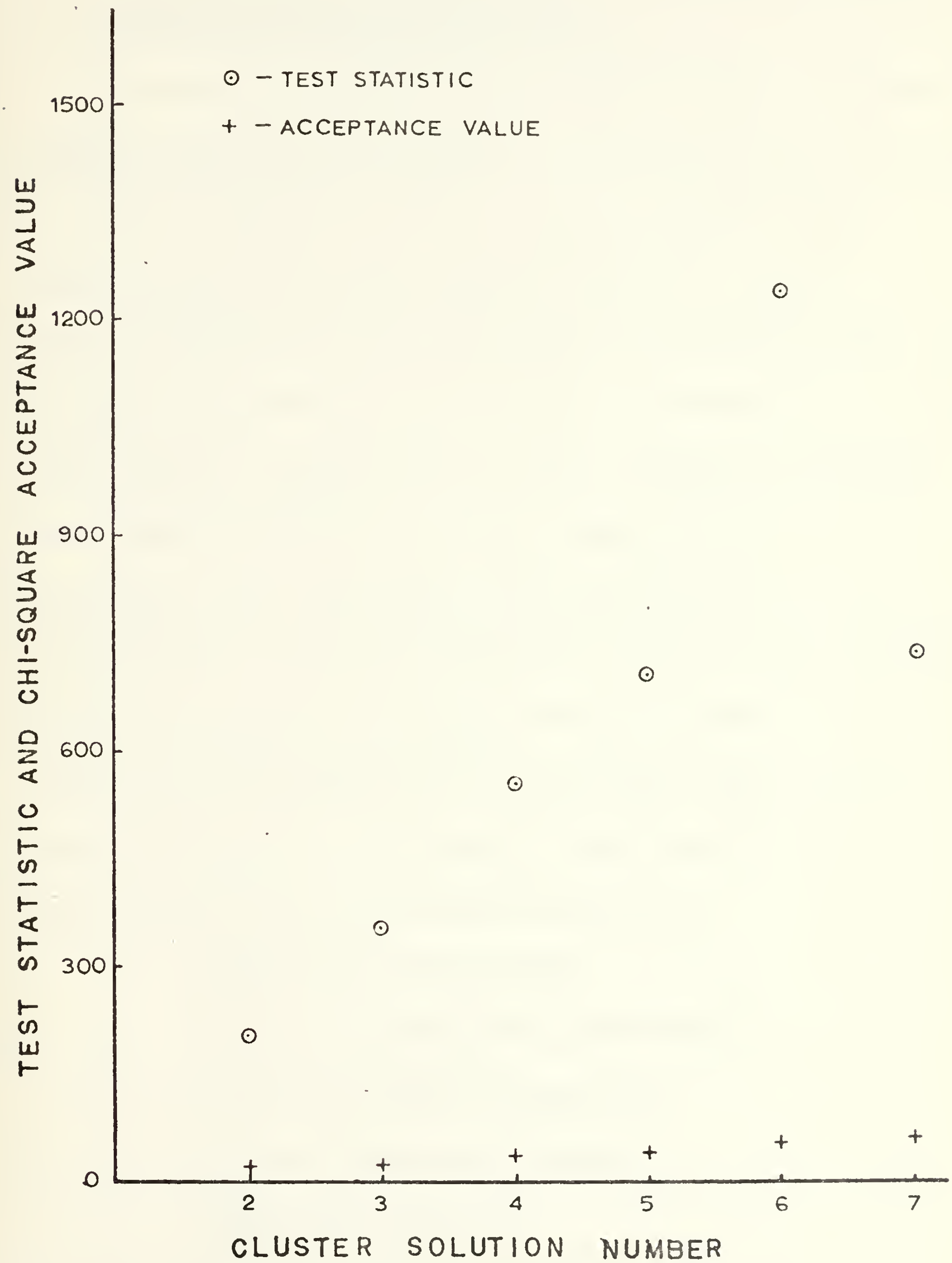
| Cluster | Instructors | Values |
|---|---|---|
| (1) | A, B, C | 1.73, 2.71, 2.94, 2.42, 1.64, 1.86, 1.79 |
| (2) | D, E, F, G, H, I, J | 3.49, 4.12, 4.56, 3.99, 3.62, 3.57, 3.41 |
| (3) | K, L, M, O, P | 4.38, 4.93, 5.17, 5.26, 4.01, 4.64, 4.55 |
| (4) | N, Q, S, T, U, V, W, Z | 4.64, 5.25, 5.33, 5.33, 5.02, 5.25, 4.88 |
| (5) | R, X | 3.57, 6.33, 6.33, 6.17, 2.08, 5.00, 5.50 |
| (6) | Y, AA, BB, CC, DD | 5.48, 6.23, 6.19, 6.37, 5.84, 6.31, 5.96 |

**7**

| Cluster | Instructors | Values |
|---|---|---|
| | A, B | 1.55, 2.18, 2.83, 2.13, 1.72, 1.58, 1.44 |
| | C, D | 2.52, 3.92, 3.60, 3.44, 1.58, 3.27, 2.78 |
| | E, F, G, H, I, L, M | 3.63, 4.24, 5.13, 4.06, 3.88, 3.69, 3.70 |
| | J, P | 4.74, 3.71, 3.84, 5.47, 4.50, 4.33, 4.19 |
| | K, O, Q, S, V, W | 4.37, 5.03, 5.02, 5.35, 4.47, 4.96, 4.65 |
| | R, X | 3.57, 6.33, 6.33, 6.17, 2.08, 5.00, 5.50 |
| | N, T, U, Y, Z, AA, BB, CC, DD | 5.20, 5.99, 5.97, 5.92, 5.56, 5.92, 5.59 |

COMPONENTS
1. ORGANIZATION AND CLARITY
2. INSTRUCTOR GRP.INTERACTION
3. INSTRUCTOR IND.INTERACTION
4. SYNTHETIC ANALYTIC APPROACH
5. EVALUATION TECHNIQUE
6. PRESENTATION TECHNIQUE(D+E)
7. STIMULATION

FIGURE 4. PLOT OF TEST STATISTIC AND CHI-SQUARE ACCEPTANCE VALUES VERSUS THE NUMBER OF CLUSTERS FOR INSTRUCTOR AVERAGED SHORT FORM SCORES FROM THE MAY 1973 MANAGEMENT 817 DATA



# IV. CONCLUSIONS

## A. DETERMINATION OF COMPONENTS OF EFFECTIVE TEACHING AT THE NAVAL POSTGRADUATE SCHOOL

The primary objective of this research was to use the methods of Hildebrand and Wilson to determine the components of effective teaching at the Naval Postgraduate School. What has been determined is that their methods will find the components of effective teaching for any group of respondents, but the solutions for one group are different from another in the number of components found, the order of the components, and the original variables that are used to interpret the components. Such differences occur even when the groups are from the same curriculum. On the other hand, there seems to be a set of components which exist to varying degrees for all groups analyzed. This set is most clearly defined in solutions for large heterogeneous groups of respondents. The seven components which define this set listed in their order of contribution to the overall variability of the Principal Components solution on all the data collected in the course of this research are:

1. ORGANIZATION AND CLARITY
2. INSTRUCTOR INDIVIDUAL INTERACTION
3. INSTRUCTOR GROUP INTERACTION
4. SYNTHETIC ANALYTIC APPROACH
5. EVALUATION TECHNIQUE
6. PRESENTATION TECHNIQUE
7. STIMULATION

TABLE XX

SUMMARY OF ALL PRINCIPAL COMPONENTS ANALYSIS SOLUTIONS

| | ORGANIZATION AND CLARITY | INSTRUCTOR INDIVIDUAL INTERACTION | INSTRUCTOR GROUP INTERACTION | SYNTHETIC ANALYTIC APPROACH | EVALUATION TECHNIQUE | PRESENTATION TECHNIQUE(D+E) | STIMULATION |
|---|---|---|---|---|---|---|---|
| DECEMBER 1971 ALL CURRICULA 1089 OBSERVATIONS | 1 | 2 | 7 | 4 | 3 | 6 | 5 |
| DECEMBER 1971 MANAGEMENT 817 498 OBSERVATIONS | 1 | 3 | 2 | 4 | 5 | 6 | 7 |
| DECEMBER 1971 COMPUTER SCIENCE MGT 402 OBSERVATIONS | 6 | 4 | 2 | 3 | x | 1 | 5 |
| DECEMBER 1971 ELECTRICAL ENGINEERING 189 OBSERVATIONS | 1 | 4 | 6 | 2 | 3 | x | 5 |
| MARCH 1972 ALL CURRICULA 278 OBSERVATIONS | 1 | 5 | 2 | 3 | x | x | 4 |
| MARCH 1972 OPERATIONS ANALYSIS 159 OBSERVATIONS | 1 | x | 2 | 3 | x | x | 4 |
| DEC 71 + MAR 72 ALL CURRICULA 1368 OBSERVATIONS | 1 | 2 | 4 | 7 | 5 | 6 | 3 |
| MARCH 1973 OPERATIONS ANALYSIS 243 OBSERVATIONS | 1 | 2 | 4 | x | 5 | x | 3 |
| MAY 1973 MANAGEMENT 817 507 OBSERVATIONS | 2/1 | 3 | 3 | 6 | 5 | x | 4 |
| DEC 71 + MAY 73 MANAGEMENT 817 995 OBSERVATIONS | 1 | 3 | 2 | 7 | 5 | 6 | 4 |
| ALL DATA 2107 OBSERVATIONS | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| HILDEBRAND AND WILSON SOLUTION | 2 | 4 | 3 | 1 | x | 5 | x |

Table XX shows a summary of all principal components solutions on various data sets and subsets collected in conjunction with this research. The last solution shown is that of Hildebrand and Wilson in their work at the University of California, Davis Campus. It is presented in support of the conclusions in the preceding paragraph.

## B. DEVELOPMENT OF A SHORT FORM QUESTIONNAIRE

In addition to the components of effective teaching, it was hoped that a short form questionnaire could be developed, using such components, that would extract an accurate representation of the students' opinion of teaching performance. The smaller number of variables would be easier to analyze and would provide useful, composite information to both the instructor and the evaluating administrator. It was shown that while the methods of Hildebrand and Wilson in this respect can be emulated, the short form developed from a parent Principal Components solution did not have a one to one correspondence of variables to the Principal Components solution for a counter part group of long form respondents. As a result, the short form was not validated and no conclusion can be made. It is felt that the approach applied to larger heterogeneous samples both for development and validation would work as it did for Hildebrand and Wilson.

## C. IDENTIFICATION OF TEACHING PATTERNS

It is concluded that teaching patterns or styles can be found using cluster analysis to group instructors on variables which are the components

of effective teaching as perceived by the student and then using discriminant analysis to find the cluster solution which is best. This method can be used for either factor scores or the short form variables developed from the Principal Components solution. On the other hand, it is not possible to make a judgement about performance of any cluster other than the extremes which have universally high or low means and are clearly the good and bad performers, respectively.

## V. COMPARISON OF RESULTS WITH OTHER WORK

At the same time this research was being carried out, another approach was being used to determine what characterized effective teaching at the Naval Postgraduate School.[17] This approach employed the method of critical incidents coupled with content analysis of statements by the respondents. There were two statements from each respondent, one describing a time when he was particularly satisfied with an instructor, the other describing when he was not. A decision tree was developed to classify key phrases and an order-of-importance listing of categories was developed. That listing follows:

1. Course Organization
2. Evaluation of Student
3. Attitude Toward Student Understanding
4. Ability to Create Learning Environment
5. Instructor Preparation
6. Ability to Explain
7. Instructor Knowledge
8. Ability to Teach at the Appropriate Level
9. Instructor Attitude Toward Course
10. Lecture Organization
11. Attitude Toward Student
12. Attitude Toward Questions
13. Student Learning Result
14. Instructor Control
15. Instructor Availability
16. Ability to Evoke Interest

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[17] Ehret, H. C. and Henson, J. N., An Analysis of Student Perceptions Concerning Instructor Effectiveness at the Naval Postgraduate School, Master of Science Thesis, Naval Postgraduate School, Monterey, California, 1973.

It is possible, by studying the comments and phrases that went into the development of this listing compared with variables that played the most important role in the development of the components of effective teaching from the principal components analysis method, to identify these categories with the components. Using the numbers that appear above:

| | |
|---|---|
| Organization and Clarity | 1, 5, 6, 10 |
| Instructor Individual Interaction | 11, 15 |
| Instructor Group Interaction | 3, 8, 12, 14 |
| Synthetic Analytic Approach | 7, 4 |
| Evaluation Technique | 2 |
| Presentation Technique (D+E) | 9 |
| Stimulation | 13, 16 |

Such identification is not completely accurate for the methods are inherently different and one tends to lose some of what the other picks up. This is understandable when one recognizes that the principal components method uses the variance structure of the data, while the tabulation of critical incidents is concerned primarily with frequency. Hence a teacher characteristic held universally salient would be picked up by the latter, but, because of the small variability, would be lost by the former. It cannot be argued that one method is better than the other, but rather they should be considered as mutually supporting.

## APPENDIX A

### SUMMARY OF ALL DATA COLLECTED

I. LONG FORM DATA

| DATE | CURRICULUM | NO. STUDENTS | NO. OBSERVATIONS | INSTRUCTORS EVALUATED |
|---|---|---|---|---|
| DEC 71 | MANAGEMENT | 49 | 498 | TOP AND BOTTOM FIVE |
| | COMPUTER SYSTEMS MANAGEMENT | 41 | 402 | |
| | ELECTRICAL ENGINEERING | 19 | 189 | |
| MAR 72 | OPERATIONS RESEARCH | 27 | 159 | TOP, MIDDLE, AND BOTTOM TWO |
| | OCEANOGRAPHY | 8 | 49 | |
| | METEOROLOGY | 12 | 70 | |
| MAR 73 | OPERATIONS RESEARCH | 28 | 243 | TOP, MIDDLE, AND BOTTOM THREE |
| MAY 73 | MANAGEMENT | 51 | 507 | TOP AND BOTTOM FIVE |

## II. SHORT FORM DATA

| DATE | CURRICULUM | QTR. | NO. STUDENTS | NO. OBSERVATIONS |
|---|---|---|---|---|
| MAR 72* | OPERATIONS RESEARCH | 8 | 31 | 372 |
| | | 6 | 51 | 612 |
| | | 4 | 63 | 756 |
| | OCEANOGRAPHY | 8 | 7 | 84 |
| | | 6 | 14 | 168 |
| | | 4 | 16 | 192 |
| | METEOROLOGY | 8 | 16 | 187 |
| | | 6 | 7 | 91 |
| | | 4 | 12 | 151 |
| MAR 73** | OPERATIONS RESEARCH | 8 | 23 | 253 |
| MAY 73 | MANAGEMENT | 4 | 33 | 363 |

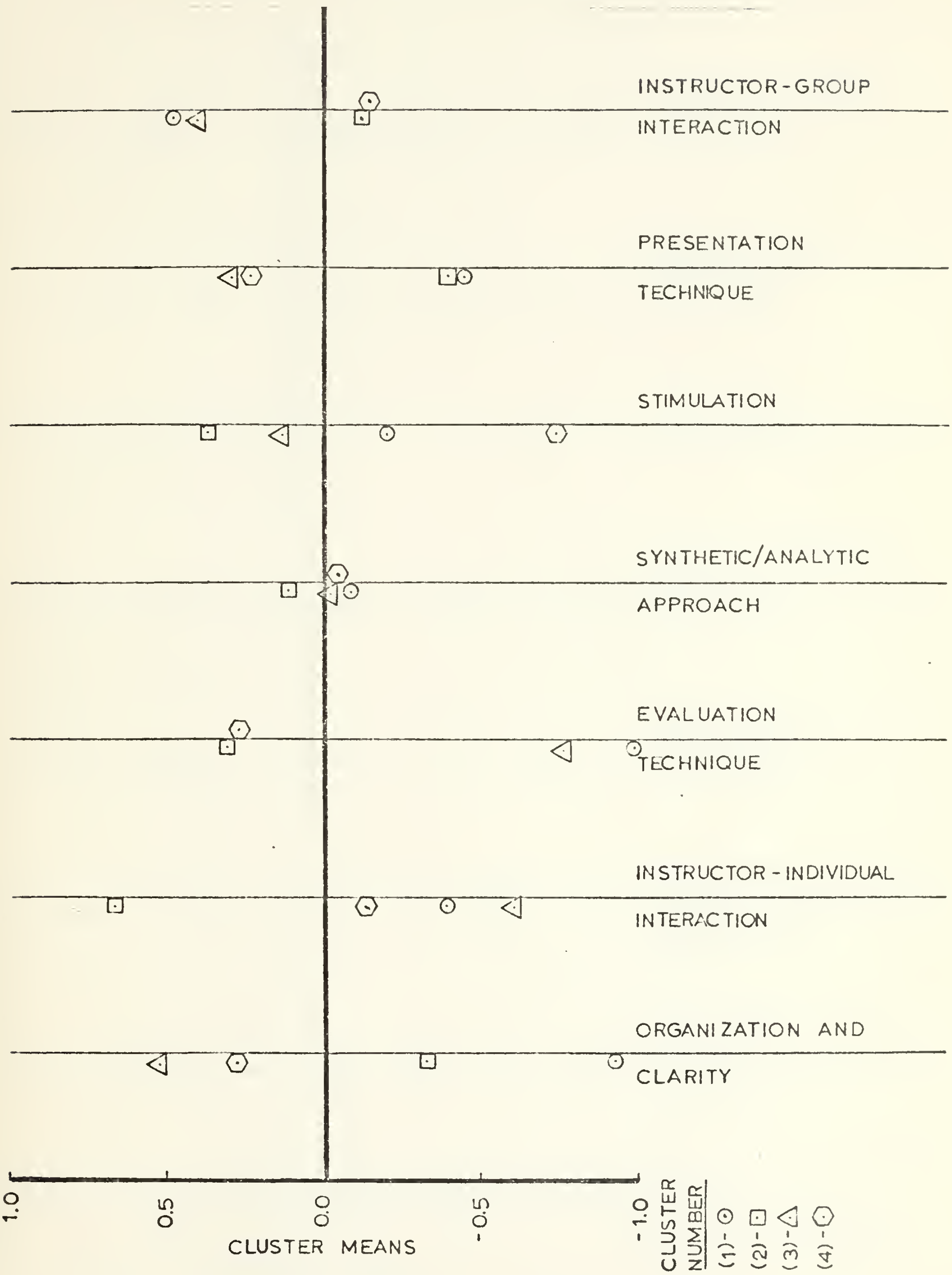
* The March 1972 short form data was based on the use of the short form variables developed by Hildebrand and Wilson. When it was discovered that there were possible additional characteristics of effective teaching perceived by students at the Naval Postgraduate School and that the order of those characteristics that were similar to theirs was not the same, efforts were devoted to development and validation of a short form based on the Naval Postgraduate School characteristics. As a result, the March 1972 short form data was not analyzed.

** The March 1973 short form data was based on an erroneous set of characteristics of effective teaching and was not analyzed.

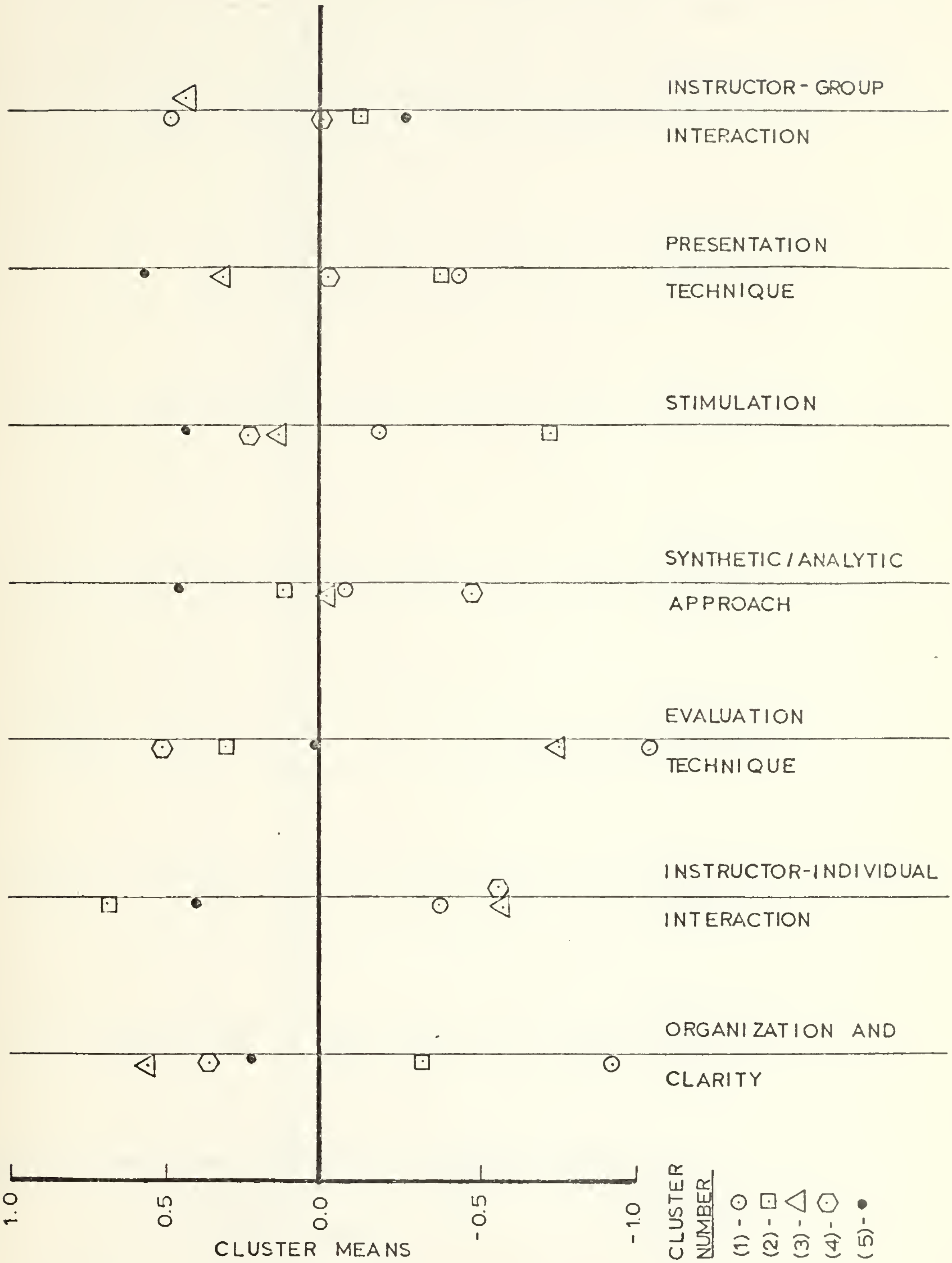
## APPENDIX B

## GRAPHICAL REPRESENTATION OF INDIVIDUAL CLUSTER MEANS FOR THE FOUR, FIVE, AND SIX CLUSTER SOLUTIONS ON THE AVERAGED FACTOR SCORES FOR THE INSTRUCTORS EVALUATED IN DECEMBER 1971 BY THE MANAGEMENT 817 CURRICULUM

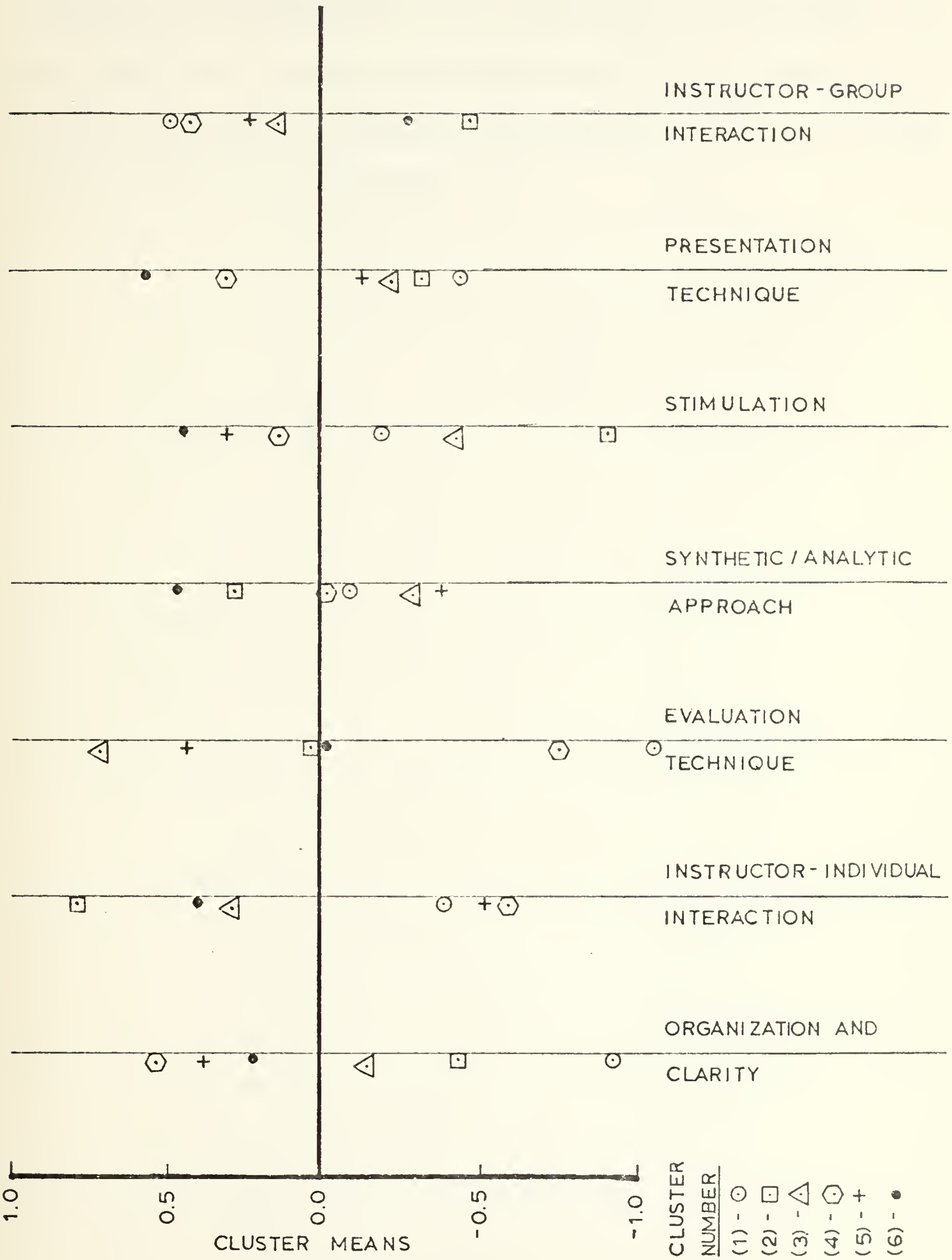
FOUR CLUSTER SOLUTION PLOT



FIVE CLUSTER SOLUTION PLOT



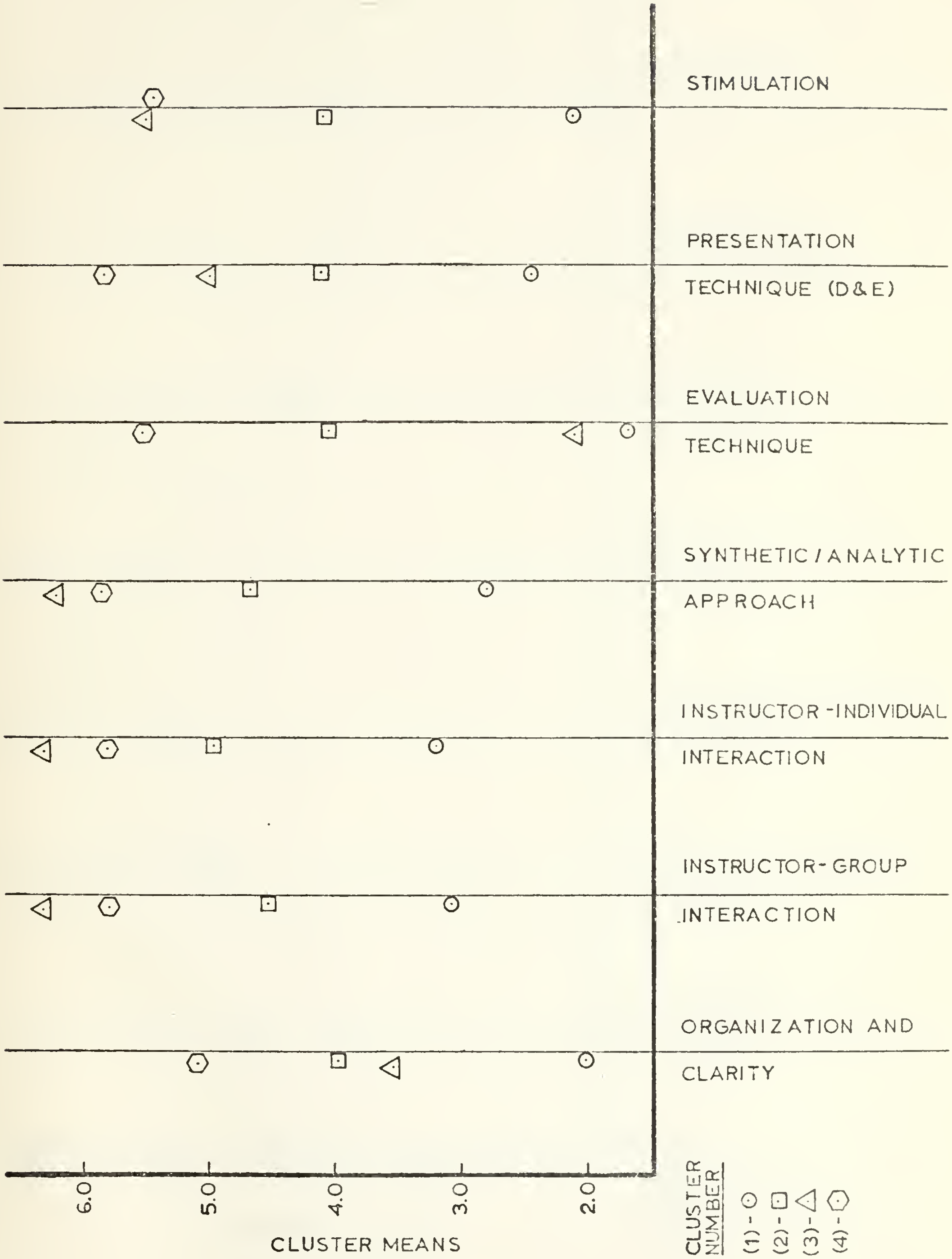
SIX CLUSTER SOLUTION PLOT



APPENDIX C

GRAPHICAL REPRESENTATION OF THE INDIVIDUAL CLUSTER MEANS FOR THE FOUR, FIVE, AND SIX CLUSTER SOLUTIONS ON THE AVERAGED SHORT FORM SCORES FOR THE INSTRUCTORS EVALUATED IN MAY 1973 BY THE MANAGEMENT 817 CURRICULUM

FOUR CLUSTER SOLUTION PLOT



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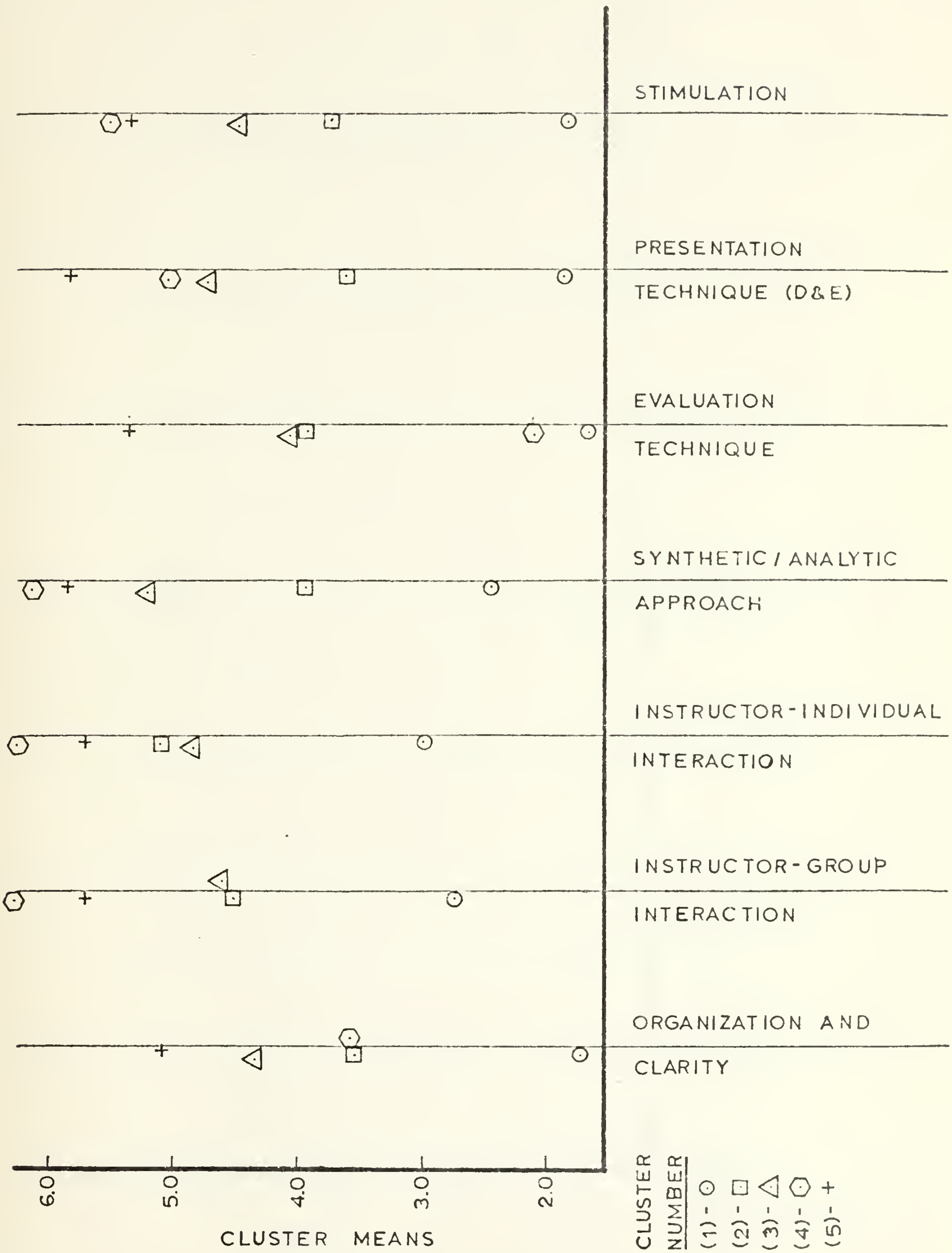

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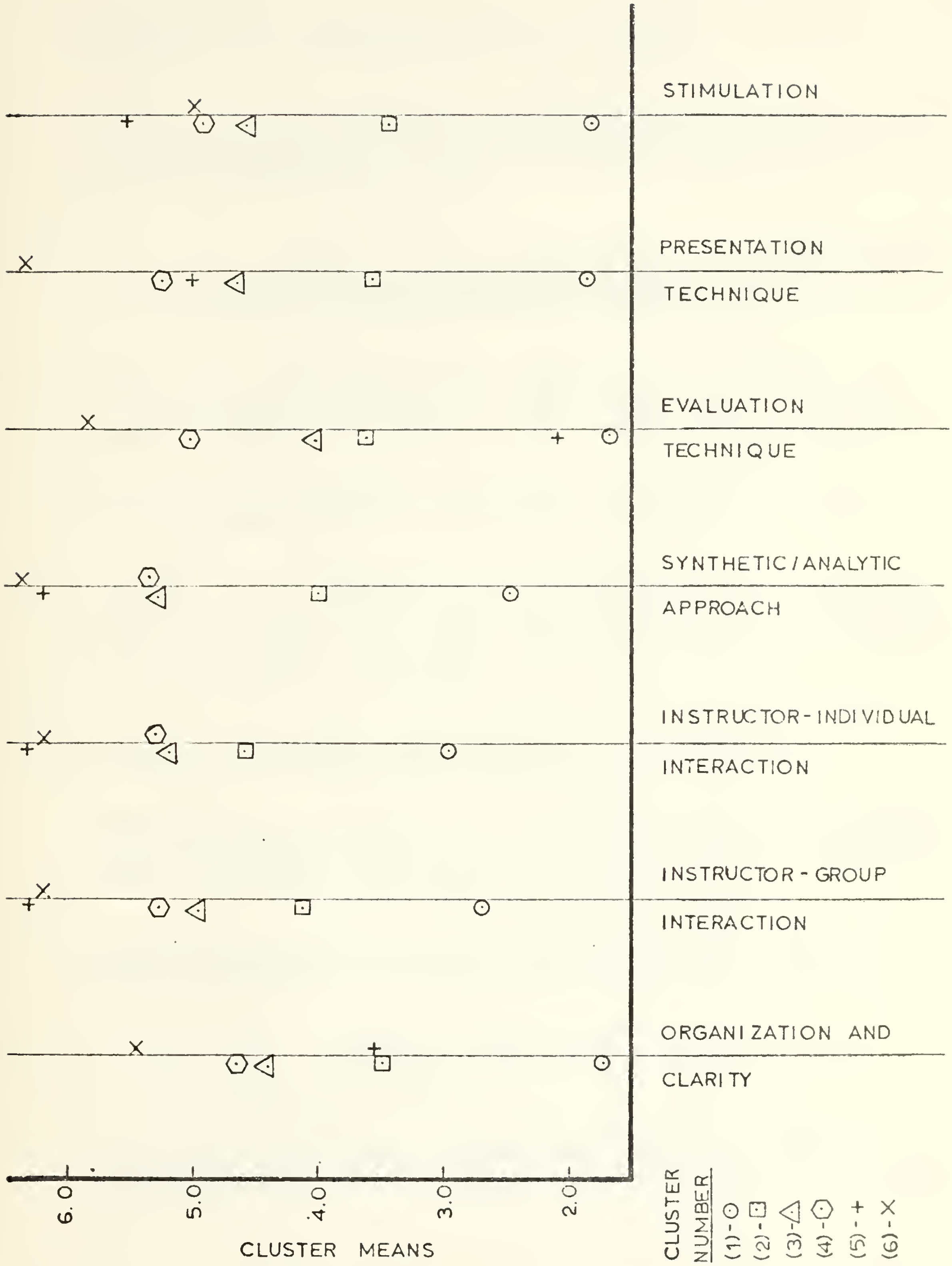

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| 7. AUTHOR(s) Clifford Thomas Burgess, Jr. Jack Allen Vaughn | | 8. CONTRACT OR GRANT NUMBER(s) |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940 | | 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS |
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| | | 13. NUMBER OF PAGES 89 |
| 14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) Naval Postgraduate School Monterey, California 93940 | | 15. SECURITY CLASS. (of this report) Unclassified |
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Principal components factor analysis
Cluster analysis
Discriminant analysis
Student opinion

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The thesis investigates the characteristics of effective teaching as perceived by students at the Naval Postgraduate School. Principal components factor analysis is used to extract the characteristics from observations on an 86 variable questionnaire form designed by Hildebrand and Wilson. The characteristics are then used as a basis for a short form questionnaire. Cluster and discriminant analysis are used to find teaching patterns or styles based on

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seven characteristics. Ranking schemes for evaluated instructors are also discussed.

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